

OXFORD IB PREPARED



CHEMISTRY

ANSWERS



IB DIPLOMA PROGRAMME

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IB Prepared Chemistry

Answers to practice problems

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1 Stoichiometric relationships

- Anode (negative electrode):**
 $\text{C}_2\text{H}_5\text{OH}(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{CH}_3\text{COOH}(\text{aq}) + 4\text{H}^+(\text{aq}) + 4\text{e}^-$

Cathode (positive electrode):
 $\text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}(\text{l})$
- Each structural unit of calcium nitrate contains three ions, one Ca^{2+} and two NO_3^- .
 Therefore, 0.25 mol of calcium nitrate will contain $3 \times 0.25 = 0.75$ mol ions.
 The number of ions will be $0.75 \text{ mol} \times 6.02 \times 10^{23} \text{ mol}^{-1} \approx 4.5 \times 10^{23}$.
- $M(\text{CH}_2\text{O}) = 12.01 + 2 \times 1.01 + 16.00 = 30.03 \text{ g mol}^{-1}$, which is twice as low as the molar mass. Therefore, one molecule of compound X contains twice as many atoms as its empirical formula, so the molecular formula of X is $\text{C}_2\text{H}_4\text{O}_2$.
- $\text{C}_x\text{H}_{2y} + (x + 0.5y)\text{O}_2 \rightarrow x\text{CO}_2 + y\text{H}_2\text{O}$

$n(\text{C}) = n(\text{CO}_2) = \frac{1.75 \text{ g}}{44.01 \text{ g mol}^{-1}} \approx 0.0398 \text{ mol}$

$n(\text{H}) = 2 \times n(\text{H}_2\text{O}) = 2 \times \frac{0.836 \text{ g}}{18.02 \text{ g mol}^{-1}} \approx 0.0928 \text{ mol}$

$\frac{n(\text{C})}{n(\text{H})} = \frac{0.0398 \text{ mol}}{0.0928 \text{ mol}} \approx \frac{3}{7}$, so the empirical formula of Y is C_3H_7 .

$M(\text{C}_3\text{H}_7) = 3 \times 12.01 + 7 \times 1.01 = 43.10 \text{ g mol}^{-1}$, which is twice as low as the molar mass of Y. Therefore, the molecular formula of Y is C_6H_{14} .
- $n(\text{NaNO}_3) = \frac{1.7 \text{ g}}{85.00 \text{ g mol}^{-1}} = 0.020 \text{ mol}$

$c(\text{NaNO}_3) = \frac{0.020 \text{ mol}}{0.10 \text{ dm}^3} = 0.20 \text{ mol dm}^{-3}$

Therefore, the correct answer is **C**.
- a)** $\text{C}_3\text{H}_8(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{l})$

b) $M(\text{C}_3\text{H}_8) = 3 \times 12.01 + 8 \times 1.01 = 44.11 \text{ g mol}^{-1}$

$n(\text{C}_3\text{H}_8) = \frac{4.00 \text{ g}}{44.11 \text{ g mol}^{-1}} \approx 0.0907 \text{ mol}$

$n(\text{O}_2) = \frac{68.2 \text{ g}}{32.00 \text{ g mol}^{-1}} \approx 2.13 \text{ mol}$

According to the equation, the complete combustion of 0.0907 mol of propane would require $5 \times 0.0907 \approx 0.454$ mol of oxygen. The amount of oxygen in the reaction mixture (2.13 mol) was greater than required, so propane was the limiting reactant.

7. According to section 1 of the data booklet, $pV = nRT$, so:

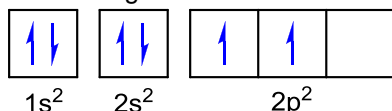
$$V = \frac{nRT}{p} = \frac{0.350 \text{ mol} \times 8.31 \text{ J mol}^{-1} \text{ K}^{-1} \times 299 \text{ K}}{1.15 \times 10^5 \text{ Pa}} \approx 7.56 \times 10^{-3} \text{ m}^3 = 7.56 \text{ dm}^3$$

Note that the pressure was converted from kPa to Pa, and the temperature from °C to K:
 $T = 26.0 + 273 = 299 \text{ K}$.

2 Atomic structure

- The correct answer is **C**.
 Note that the positive charge (2+) means that the ion has two fewer electrons than protons.
- UV photons are produced by excited hydrogen atoms when their electrons fall from higher energy levels to the ground level ($n = 1$). Therefore, the correct answer is **C**.
- The electron configuration of Cu^{2+} is $[\text{Ar}]3d^9$, so one orbital of the 3d sublevel contains a single electron. All other orbitals in this ion are either full (contain electron pairs) or empty, so the correct answer is **B**.

- Nucleus: six protons and seven neutrons.
 Orbital diagram:



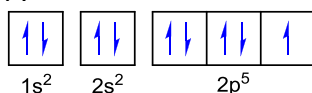
- The heights of the first and second peaks are approximately 69% and 31%, respectively. Therefore:

$$A_r = \frac{61 \times 69\% + 65 \times 31\%}{100\%} \approx 62$$
 - The element with the closest atomic mass is copper ($A_r = 63.55$). The difference in atomic mass is probably caused by the unusual isotopic composition of the studied sample.
- Many characteristics of isolated atoms, such as the density of their electron clouds or their ability to interact with other atoms, are spherically symmetrical and change steeply at a certain distance from the nucleus, so it's logical to represent the atom as a ball or sphere with a radius equal to that distance. In addition, atoms are quantum objects with no definite shapes or sizes, which justifies the use of simplest geometric figures (balls or spheres) for their visualisation. Finally, it is difficult to draw or display an object without a surface while a sphere can be easily represented on paper or computer screen.

- $\text{Ga}: 1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^1$
 $\text{P}^{3-}: 1s^2 2s^2 2p^6 3s^2 3p^6$
 $\text{V}^{2+}: 1s^2 2s^2 2p^6 3s^2 3p^6 3d^3$

- $[\text{Ar}] 3d^3$

- F:



- Ni^{2+} :



In both cases, full or condensed electron diagrams are acceptable.

3 Periodicity

- The correct answer is **B**.
- Electron configuration: $1s^2 2s^2 2p^6 3s^2 3p^4$, or $[\text{Ne}]3s^2 3p^4$.
The period number shows the highest energy level (partly) filled with electrons. In sulfur, it is the third level, so this element belongs to the third period.
For main group elements, the group number is equal to the number of outer electrons plus 10. Sulfur has six outer electrons (two on the 3s and four on the 3p sublevel), so this element belongs to group 16 (as $6 + 10 = 16$).
 - Cu^{2+} : $[\text{Ar}]3d^9$
 Zn^{2+} : $[\text{Ar}]3d^{10}$
Copper forms ions with an incomplete 3d sublevel, so it is a transition element by definition. The 3d sublevel in zinc and all its known ions is complete, so zinc is not a transition element.
- Metals: Ba only. Metalloids: Ge and Si. Non-metals: I, Kr and H.
- The first electron in boron is lost from the 2p sublevel, which produces a relatively stable configuration with one full sublevel ($2s^2$) and one empty sublevel ($2p^0$). In contrast, the first electron in beryllium is lost from the 2s sublevel, which produces a less stable configuration with an incomplete sublevel ($2s^1$). Therefore, boron loses an electron more readily than beryllium and thus has a lower first ionization energy.
 - The situation is similar to that in (a). The loss of one electron changes the configuration of the 2p sublevel in nitrogen from $2p^3$ (half-full and thus relatively stable) to $2p^2$ (neither empty, nor full, nor half-full, and thus less stable). In the case of oxygen, the loss of one electron changes the configuration of the 2p sublevel from $2p^4$ (neither empty, nor full, nor half-full, and thus less stable) to $2p^3$ (half-full and thus more stable). Therefore, oxygen loses an electron more readily than nitrogen and thus has a lower first ionization energy.

4 Chemical bonding and structure

- PCl_3 : $\chi(\text{P}) = 2.2$, $\chi(\text{Cl}) = 3.2$, $\Delta\chi = 3.2 - 2.2 = 1.0$, hence polar covalent bond.
 HCl : $\chi(\text{H}) = 2.2$, $\chi(\text{Cl}) = 3.2$, $\Delta\chi = 3.2 - 2.2 = 1.0$, hence polar covalent bond.
 MgF_2 : $\chi(\text{Mg}) = 1.3$, $\chi(\text{F}) = 4.0$, $\Delta\chi = 4.0 - 1.3 = 2.7$, hence ionic bond.
- Bond length decreases as follows: single > double > triple. The only compound with a triple carbon-to-oxygen bond is carbon monoxide, CO, so the correct answer is **A**.
- In water, each covalent bond is formed by pairing single electrons from participating atoms. In ammonium, nitrogen donates a lone electron pair to the empty orbital of a hydrogen cation, thus forming a coordinate bond. Similarly, the coordinate bond in carbon monoxide is formed from a lone electron pair of oxygen and an empty orbital of carbon. Therefore, the correct answer is **C**.

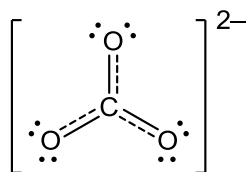
4. a)

Species	Lewis structure	Electron domain geometry	Molecular geometry	Bond angle(s)
$[\text{BF}_4]^-$		tetrahedral	tetrahedral	109.5°
H_2S		tetrahedral	V-shaped (bent)	$< 109.5^\circ$
BF_2Cl		trigonal planar	trigonal planar	$\approx 120^\circ$
CO_3^{2-}		trigonal planar	trigonal planar	120°

Note that the negative signs in the Lewis structures of $[\text{BF}_4]^-$ and CO_3^{2-} can also be shown at the B and O atoms, respectively. For CO_3^{2-} , three equivalent Lewis structures are possible.

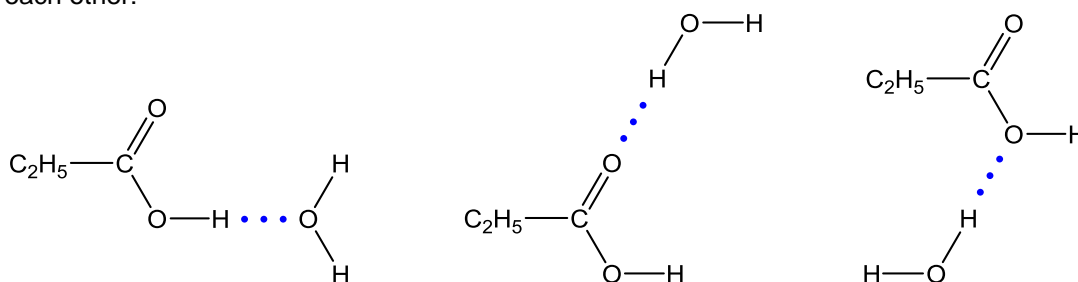
The F–B–F and F–B–Cl bond angles in BF_2Cl differ slightly due to uneven distribution of electron density within the molecule. However, this difference is very small, so the answer " 120° " is also acceptable.

- b) Both molecules are polar. In H_2S , the dipoles of S–H bonds are positioned at an angle to each other and not cancelled by the dipoles of the lone electron pairs. In BF_2Cl , the dipoles of B–F and B–Cl do not cancel each other due to the different electronegativities and covalent radii of fluorine and chlorine.
- c) Resonance structure:



All three carbon-to-oxygen bonds in this ion have the same length, as the distribution of electron density is symmetrical. The exact length of these bonds is intermediate between the lengths of a single and a double carbon-to-oxygen bonds.

5. There are three ways in which propanoic acid and water can form hydrogen bonds with each other:



Any two of these or similar diagrams are likely to score the full mark at the examination.

6. In contrast to HCl, the molecules of HF can form hydrogen bonds with one another. Therefore, HF has a higher boiling point than HCl.
7. a) methanal hydrogen peroxide fluoromethane
- b) Only the molecules of hydrogen peroxide can form hydrogen bonds with one another, so this substance is likely to be liquid at 298 K.
8. Both elements form metallic lattices, in which metal cations are held together by the sea of delocalised electrons. However, doubly charged ions of magnesium, Mg^{2+} , experience a stronger electrostatic attraction to the delocalised electrons than singly charged ions of sodium, Na^+ . A stronger metallic lattice requires more energy to break, so the melting point of magnesium metal is higher than that of sodium metal.

5 Energetics/thermochemistry

1. a) Your answer can include any two of the following assumptions:
- no heat was lost to the environment;
 - the heat capacity of the calorimeter/thermometer/zinc metal was negligible;
 - the specific heat capacity of the solution was the same as that of water;
 - the change in mass of the solution during the reaction was negligible.
- b) i) If no heat were lost, and the reaction were instantaneous, the temperature would rise instantly from 24.5 to 73.0°C. Therefore, the temperature change would be $73.0 - 24.5 = 48.5^\circ\text{C}$.
- Note that the highest estimated temperature (73.0°C) can either be found as the point on the dashed red line at $t = 100$ s or calculated from the equation $T = -0.050t + 78.0$.
- ii) During the reaction, the mixture was losing heat to the environment at a constant rate.
- iii) Since the density of the solution is not given, we can only assume that the solution was dilute, and its density was approximately the same as that of water (1.00 kg dm^{-3}). Therefore:
- $$m(\text{solution}) = 0.050 \text{ dm}^3 \times 1.00 \text{ kg dm}^{-3} = 0.050 \text{ kg}$$
- $$\text{Heat change} = 0.050 \text{ kg} \times 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1} \times 48.5 \text{ K} \approx 10 \text{ kJ}$$

- c) Since the solution became colourless, all copper(II) ions had reacted with zinc metal. Therefore, $\text{Cu}^{2+}(\text{aq})$ was the limiting reactant while $\text{Zn}(\text{s})$ was in excess.
 $n(\text{Cu}^{2+}) = 0.050 \text{ dm}^3 \times 1.00 \text{ mol dm}^{-3} = 0.050 \text{ mol}$
 $\Delta n(\text{Zn}) = n(\text{Cu}^{2+}) = 0.050 \text{ mol}$

d)
$$\Delta H^\circ = -\frac{\text{heat released}}{\Delta n} = -\frac{10 \text{ kJ}}{0.050 \text{ mol}} = -200 \text{ kJ mol}^{-1}$$

Since the reaction involves one mole of each ion, $\Delta H^\circ_r = -200 \text{ kJ}$.

Note that the reaction was exothermic, so $\Delta H^\circ_r < 0$.

2. To produce the final equation, we need to add together the first two equations. Therefore, their enthalpy values will be added together as well:

$$\Delta H = \Delta H_1 + \Delta H_2 = +182.6 \text{ kJ} + (-116.2 \text{ kJ}) = +66.4 \text{ kJ}$$

3. a) $\Delta H^\circ = -1675.7 - (-824.2) = -851.5 \text{ kJ}$

Note that the ΔH°_f values for elementary substances, $\text{Al}(\text{s})$ and $\text{Fe}(\text{s})$, are zero.

- b) Since $\Delta H^\circ < 0$, the reaction is exothermic.

4. a) $\text{C}_2\text{H}_5\text{OH}(\text{l}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + 3\text{H}_2\text{O}(\text{l})$

Bonds broken:

$$5 \times \text{C-H} + 1 \times \text{C-C} + 1 \times \text{C-O} + 1 \times \text{O-H} + 3 \times \text{O=O}$$

$$\Delta H = 5 \times 414 + 346 + 358 + 463 + 3 \times 498 = 4731 \text{ kJ}$$

Bonds formed:

$$4 \times \text{C=O} + 6 \times \text{O-H}$$

$$\Delta H = 4 \times 804 + 6 \times 463 = 5994 \text{ kJ}$$

$$\Delta H^\circ_c = 4731 - 5994 = -1263 \text{ kJ mol}^{-1}$$

- b) There are two reasons. First, bond enthalpies are averaged over many compounds, so their values for specific compounds can differ slightly. Second, bond enthalpies are calculated for gaseous species while the ΔH°_c value $-1367 \text{ kJ mol}^{-1}$ given in section 13 of the data booklet is calculated for liquid ethanol.

5. According to sections 1 and 2 of the data booklet, $E = h\nu$, where $h = 6.63 \times 10^{-34} \text{ J s}$, and $c = \nu\lambda$, where $c = 3.00 \times 10^8 \text{ m s}^{-1}$. Therefore:

$$E = \frac{\Delta H}{N_A} = \frac{362000 \text{ J mol}^{-1}}{6.02 \times 10^{23} \text{ mol}^{-1}} \approx 6.01 \times 10^{-19} \text{ J}$$

$$\nu = \frac{E}{h} = \frac{6.01 \times 10^{-19} \text{ J}}{6.63 \times 10^{-34} \text{ J s}} \approx 9.06 \times 10^{14} \text{ s}^{-1}$$

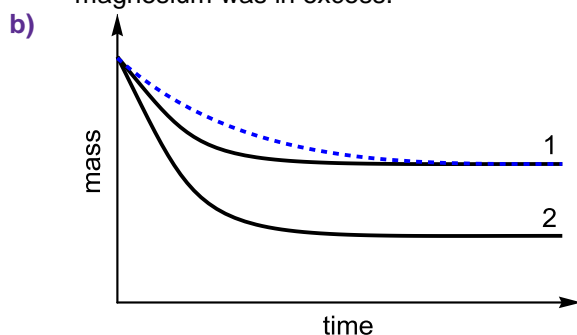
$$\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^8}{9.06 \times 10^{14} \text{ s}^{-1}} \approx 3.31 \times 10^{-7} \text{ m} = 331 \text{ nm}$$

6 Chemical kinetics

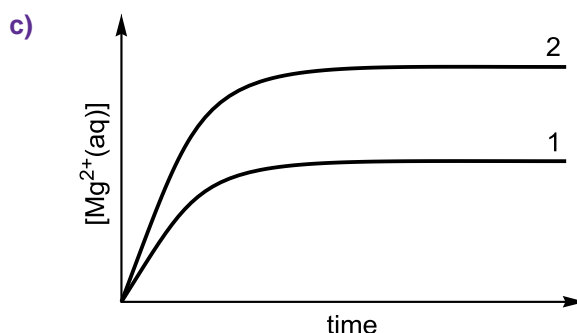
- The correct answer is **D**, as the use of concentrated acid would increase the quantity of the limiting reactant, HCl(aq) , which would cause a greater mass loss. In all other cases the curves would flatten out on the same level as curve 1, as these changes do not affect the quantity of the limiting reactant.

- At first, hydrogen gas is released at a certain rate, so the mass of the beaker with its contents decreases. As the acid is consumed, its concentration decreases, so the frequency of collisions between $\text{H}^+(\text{aq})$ ions and Mg(s) also decreases. As a result, the curve becomes less steep. When the acid is consumed completely, the release of gas stops, and the curve flattens out.

Note that the answer "magnesium is consumed completely" would cost you a mark, as magnesium was in excess.



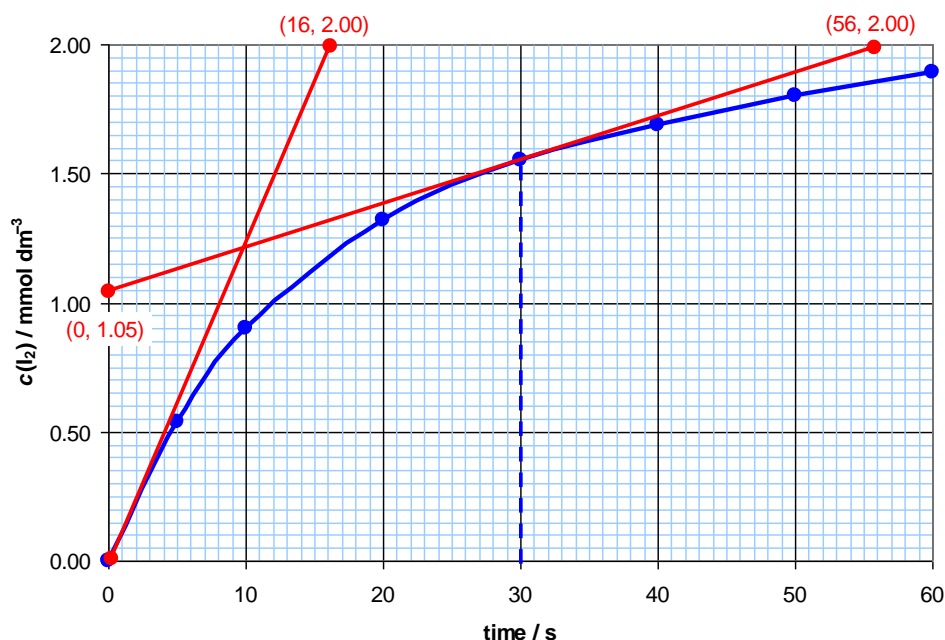
Note that the curve is less steep than curve 1 but flattens out on the same level. The final mass loss is controlled by the quantity of the limiting reactant, HCl(aq) , which is not affected by temperature.



Note that both curves must begin at origin, as the initial solution does not contain $\text{Mg}^{2+}(\text{aq})$.

- Iodine is coloured while all other reactants and products are colourless. Therefore, the concentration of iodine can be monitored by a colorimeter. Alternatively, the pH of the solution can be monitored by a pH-meter, as $\text{H}^+(\text{aq})$ ions are consumed during the reaction.

b) i)



$$\text{ii)} \quad \text{rate}_{\text{avr30}}(\text{I}_2) = \frac{\Delta c(\text{I}_2)}{\Delta t} = \frac{1.55 - 0}{30 - 0} \approx 0.052 \text{ mmol dm}^{-3} \text{ s}^{-1} = 5.2 \times 10^{-5} \text{ mol dm}^{-3} \text{ s}^{-1}$$

Note that $c(\text{I}_2)$ in the table is given in mmol dm^{-3} , so a conversion factor ($1 \text{ mmol} = 10^{-3} \text{ mol}$) must be applied.

iii) To find the initial rate, we need to draw a tangent line to the curve at $t = 0$ and take any two points on this line (ideally, as far apart as possible), for example, (0, 0) and (16, 2.00):

$$\text{rate}_{\text{init}}(\text{I}_2) = \frac{2.00 - 0}{16 - 0} = 0.125 \text{ mmol dm}^{-3} \text{ s}^{-1} \approx 1.3 \times 10^{-4} \text{ mol dm}^{-3} \text{ s}^{-1}$$

For the instantaneous rate at $t = 30 \text{ s}$ we need to draw a tangent line to the curve at that time and take any two points, for example, (0, 1.05) and (56, 2.00):

$$\text{rate}_{\text{inst30}}(\text{I}_2) = \frac{2.00 - 1.05}{56 - 0} \approx 0.017 \text{ mmol dm}^{-3} \text{ s}^{-1} = 1.7 \times 10^{-5} \text{ mol dm}^{-3} \text{ s}^{-1}$$

iv) The stoichiometric coefficient before $\text{I}_2(\text{aq})$ in the equation is 3, so the overall initial rate will be three times lower than the initial rate with respect to $\text{I}_2(\text{aq})$:

$$\text{rate}_{\text{init}} = \frac{1}{3} \text{rate}_{\text{init}}(\text{I}_2) = \frac{0.125}{3} \text{ mmol dm}^{-3} \text{ s}^{-1} \approx 4.2 \times 10^{-5} \text{ mol dm}^{-3} \text{ s}^{-1}$$

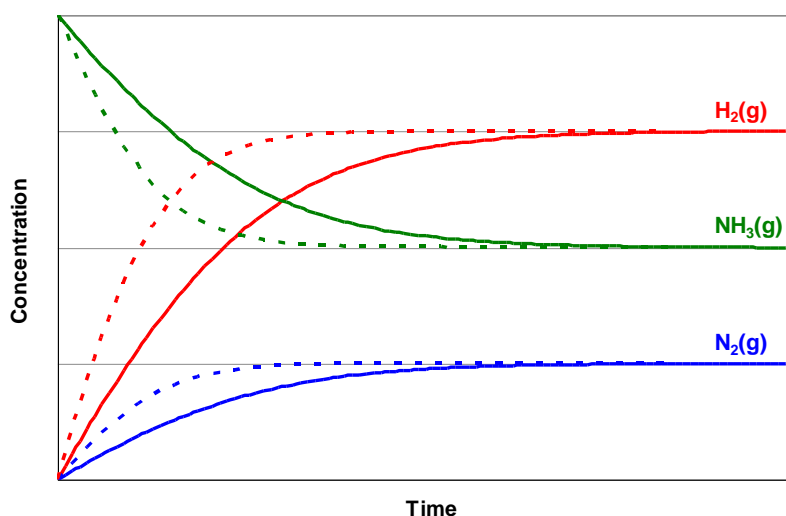
7 Equilibrium

1. The correct answer is **B**, as $Q_c < K_c$, so the forward reaction is favoured.

2. a)
$$K_c = \frac{[\text{N}_2][\text{H}_2]^3}{[\text{NH}_3]^2}$$

b) $\Delta H_r^\circ > 0$ (see table 7.1.2 in the main text).

- c) The new time–concentration curves are shown as dashed lines below.



Note that the catalyst increases the rates of both the forward and the reverse reactions by the same proportion but does not affect the equilibrium position. As a result, all curves become steeper but flatten out at their original levels.

8 Acid and bases

- The correct answer is **B**, as metal carbonates react with acids to produce carbon dioxide:
 $\text{CaCO}_3(\text{s}) + 2\text{HNO}_3(\text{aq}) \rightarrow \text{Ca}(\text{NO}_3)_2(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
- The correct answer is **C**, as $[\text{H}^+]$ at $\text{pH} = 10$ is $10^{-10} \text{ mol dm}^{-3}$ while $[\text{H}^+]$ in pure water ($\text{pH} = 7$) is $10^{-7} \text{ mol dm}^{-3}$, so $10^{-10}:10^{-7} = 1:1000 = 1:10^3$.
- Conjugate acid–base pairs (any one will score the first mark):
 H_2CO_3 (acid) and HCO_3^- (base)
 HCO_3^- (acid) and CO_3^{2-} (base)
 H_3O^+ (acid) and H_2O (base)
 H_2O (acid) and OH^- (base)

Amphiprotic species:

$\text{H}_2\text{O}(\text{aq})$ and $\text{HCO}_3^-(\text{aq})$

Note that OH^- and H_2CO_3 are also amphiprotic, as each species can lose and gain a proton. However, their conjugates O^{2-} and H_3CO_3^+ , respectively, do not exist in aqueous solutions, so these answers will not be accepted.

- $\text{Ba}(\text{OH})_2(\text{aq}) \rightarrow \text{Ba}^{2+}(\text{aq}) + 2\text{OH}^-(\text{aq})$
 Note that barium hydroxide is a strong base, so its dissociation is irreversible, and a straight arrow should be used.
 $[\text{OH}^-] = 2 \times c(\text{Ba}(\text{OH})_2) = 2 \times 2.00 \times 10^{-3} = 4.00 \times 10^{-3} \text{ mol dm}^{-3}$

$$[\text{H}^+] = \frac{K_w}{[\text{OH}^-]} = \frac{1.00 \times 10^{-14}}{4.00 \times 10^{-3}} = 2.5 \times 10^{-12} \text{ mol dm}^{-3}$$

 $\text{pH} = -\log[\text{H}^+] = -\log(2.5 \times 10^{-12}) \approx 11.60$
- $\text{H}_2\text{SO}_4(\text{aq}) + \text{Zn}(\text{s}) \rightarrow \text{ZnSO}_4(\text{aq}) + \text{H}_2(\text{g})$ (molecular equation)
 $2\text{H}^+(\text{aq}) + \text{Zn}(\text{s}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{H}_2(\text{g})$ (net ionic equation)
 An ionic equation involving hydronium ions, $\text{H}_3\text{O}^+(\text{aq})$, would also be acceptable:
 $2\text{H}_3\text{O}^+(\text{aq}) + \text{Zn}(\text{s}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{H}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})$

9 Redox processes

1. MnO_2 : manganese(IV) oxide
 Fe(OH)_2 : iron(II) hydroxide
 $\text{Cr}_2(\text{SO}_4)_3$: chromium(III) sulfate

2. a)

Step	Oxidizing agent	Reducing agent
1	$\text{O}_2(\text{aq})$	$\text{Mn}^{2+}(\text{aq})$
2	$\text{MnO}_2(\text{s})$	$\text{I}^-(\text{aq})$
3	$\text{I}_2(\text{aq})$	$\text{S}_2\text{O}_3^{2-}(\text{aq})$

- b) According to the third equation, $n(\text{I}_2) = 0.5 \times n(\text{I}^-) = 0.5 \times 0.00150 \text{ mol} = 0.000750 \text{ mol}$.

According to the second equation, $n(\text{MnO}_2) = n(\text{I}_2) = 0.000750 \text{ mol}$.

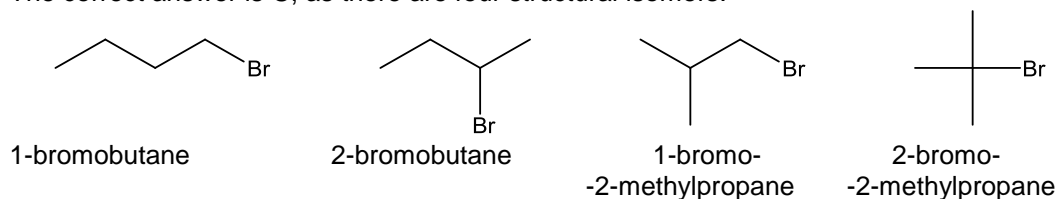
According to the first equation, $n(\text{O}_2) = 0.5 \times n(\text{MnO}_2) = 0.5 \times 0.000750 \text{ mol} = 0.000375 \text{ mol} = 3.75 \times 10^{-4} \text{ mol}$.

An alternative solution is based on the electron balance. Each $\text{O}_2(\text{aq})$ accepts four electrons while each $\text{I}^-(\text{aq})$ loses one electron, so the ratio of $\text{O}_2(\text{aq})$ to $\text{I}^-(\text{aq})$ is 1 : 4. Therefore, $n(\text{O}_2) = 0.00150 \text{ mol} / 4 = 3.75 \times 10^{-4} \text{ mol}$.

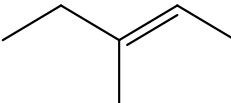
3. According to the first equation, Zn is more active than Fe. The first equation shows that Fe is more active than Ni. Finally, the last equation shows that nickel is more active than lead. Therefore, the correct answer is **B**.
4. a) Molten zinc chlorides consists of Zn^{2+} and Cl^- ions. These ions move freely and carry electric charge.
- b) Oxidation occurs at the anode while reduction occurs at the cathode.
- c) Anode (positive electrode): $2\text{Cl}^- \rightarrow \text{Cl}_2(\text{g}) + 2\text{e}^-$
 Cathode (negative electrode): $\text{Zn}^{2+} + 2\text{e}^- \rightarrow \text{Zn}(\text{l})$

10 Organic chemistry

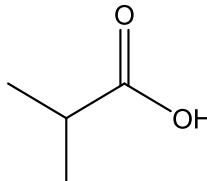
1. The correct answer is **C**, as there are four structural isomers:



Note that 2-bromobutane is chiral and thus can exist as two optical isomers, (*R*)-2-bromobutane and (*S*)-2-bromobutane, but optical isomers are not structural isomers.

2. a)
- 

3-methylpent-2-ene

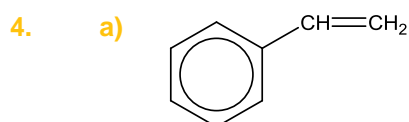


2-methylpropanoic acid

Note that the question does not specify the type of structural formula, so full or condensed formulas, such as $\text{CH}_3\text{CH}_2\text{C}(\text{CH}_3)=\text{CHCH}_3$ and $(\text{CH}_3)_2\text{CHCOOH}$, would also be acceptable.

- b) The molecules of 3-methylpent-2-ene are held together by weak London dispersion forces while the molecules of 2-methylpropanoic acid form much stronger hydrogen bonds with one another. Therefore, the boiling point of 3-methylpent-2-ene is much lower than that of 2-methylpropanoic acid.
3. a) $\text{CH}_3\text{CH}=\text{CHCH}_3 + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{CH}(\text{OH})\text{CH}_2\text{CH}_3$
- b) *Reaction type:* electrophilic addition (A_E).
Catalyst: an inorganic acid, such as H_2SO_4 or H_3PO_3 . The answer " H^+ " or " H_3O^+ " is also acceptable.
 Note that hydrochloric acid, $\text{HCl}(\text{aq})$, cannot be used here, as it will react with the alkene:
 $\text{CH}_3\text{CH}=\text{CHCH}_3 + \text{HCl} \rightarrow \text{CH}_3\text{CH}(\text{Cl})\text{CH}_2\text{CH}_3$
- c) Butan-2-ol.
- d) A hot acidified aqueous solution of potassium dichromate, $\text{K}_2\text{Cr}_2\text{O}_7(\text{aq})/\text{H}^+(\text{aq})$, will oxidise the secondary alcohol butan-2-ol to butanone, $\text{CH}_3\text{C}(\text{O})\text{CH}_2\text{CH}_3$, so the orange colour of the initial solution will change to green. The tertiary alcohol 2-methylpropan-2-ol will not react with the acidified potassium dichromate, so the solution will stay orange.

Note that the observable changes (colour change in the first case and no colour change in the second case) must be stated to score the full mark.



A more condensed structural formula, such as $\text{C}_6\text{H}_5\text{CH}=\text{CH}_2$, would also be acceptable here.

- b) No, as it has two more C and two more H atoms than benzene (the difference is C_2H_2). Homologues differ from one another by one or more CH_2 groups.
5. Functional group in **A**: hydroxyl, $-\text{OH}$. Functional group in **B**: carbonyl, $>\text{C}=\text{O}$. Note that the answers "alcohol" and "ketone" are incorrect, as these are class names, not functional group names.

The key to the correct answer is the statement "lower molecular mass". At reflux, acidified potassium dichromate (denoted below as "[O]") will oxidise primary alcohols and aldehydes to carboxylic acids while secondary alcohols will be oxidised to ketones:



In the first two reactions, the molecular mass of the product will be higher than that of the starting material while in the third reaction the product will have a lower molecular mass than the starting material. Therefore, compound **A** is a secondary alcohol and compound **B** is a ketone.

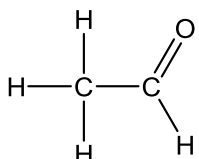
11 Measurement and data processing

- The correct answer is **B**. All other answers describe systematic errors.
- $[\text{H}_3\text{O}^+] = 10^{-\text{pH}} = 10^{-7.40} \approx 4.0 \times 10^{-8} \text{ mol dm}^{-3}$.
Note that the number of significant figures in the answer is equal to the number of *decimal places* in the exponent.
- Either $V \propto T$, or $\frac{V}{T} = \text{const}$, or $V = m \times T$, where m is a constant. To produce a linear graph, the dependent variable V should be plotted as a function of the independent variable T .
- The Arrhenius equation can be rewritten as follows:
$$\ln k = -\frac{E_a}{R} \times \frac{1}{T} + \ln A$$

Now it is obvious that the expression $-\frac{E_a}{R}$ before the independent variable $\left(\frac{1}{T}\right)$ is the slope m while the constant $\ln A$ is the intercept b . Therefore, the correct answer is **B**.
- The molecular formula of morphine is $\text{C}_{17}\text{H}_{19}\text{N}_1\text{O}_3$, so $\text{IHD} = 0.5(2 \times 17 + 2 - 19 + 1) = 9$
 - $\text{IHD} = 0.5(2 \times 12 + 2 - 18 - 2 + 2) = 4$
- Compound X contains only three elements, so $\%(\text{O}) = 100\% - 54.5\% - 9.2\% = 36.3\%$.
Let $m(\text{X}) = 100 \text{ g}$, then $m(\text{C}) = 54.5 \text{ g}$, $m(\text{H}) = 9.2 \text{ g}$ and $m(\text{O}) = 36.3 \text{ g}$.
$$n(\text{C}) : n(\text{H}) : n(\text{O}) = \frac{54.5 \text{ g}}{12.01 \text{ g mol}^{-1}} : \frac{9.2 \text{ g}}{1.01 \text{ g mol}^{-1}} : \frac{36.3 \text{ g}}{16.00 \text{ g mol}^{-1}}$$

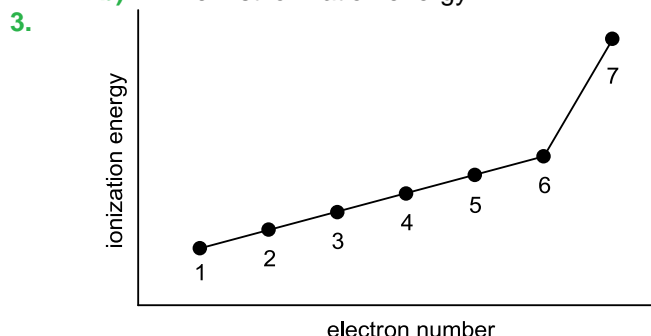
$$\approx 4.54 : 9.1 : 2.27 \approx 2 : 4 : 1$$

Therefore, the empirical formula of X is $\text{C}_2\text{H}_4\text{O}_1$.
 $M_r(\text{C}_2\text{H}_4\text{O}_1) = 2 \times 12.01 + 4 \times 1.01 + 16.00 = 44.06$. This value is very close to the m/z of the molecular ion (44) of X in the mass spectrum, so the molecular formula of X is the same as its empirical formula, $\text{C}_2\text{H}_4\text{O}_1$.
 - $\text{IHD} = 0.5(2 \times 2 + 2 - 4) = 1$.
Note that the IHD value suggests that the molecule of X contains either a double bond or a ring.
 - The strong absorption at 1725 cm^{-1} in the IR spectrum of X suggests the presence of a $\text{C}=\text{O}$ bond (a carbonyl group) while the absorption at 2976 cm^{-1} is produced by $\text{C}-\text{H}$ bonds. The only possible carbonyl compound with the molecular formula $\text{C}_2\text{H}_4\text{O}_1$ is ethanal, CH_3CHO :


 - The peak with $m/z = 29$ is likely to be produced by the CHO^+ ion.
 - Two signals (one of the CH_3 protons and another of the CHO proton).
 - CH_3 protons: 2.2–2.7 ppm. CHO proton: 9.4–10 ppm.

12 Atomic structure (AHL)

- The large difference between the last two ionization energies suggests that the fifth electron is lost from a lower energy level than the first four electrons. Therefore, the unknown element has four electrons in the outer energy level and thus belongs to group 14, so the correct answer is **C**.
- As the electron moves further away from the nucleus, the energy levels become closer together. The higher the energy level, the weaker the electrostatic attraction between the electron and the nucleus, and thus the less energy is required to promote the electron to the next level.
 - The first ionization energy.

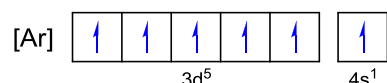


To score the full mark, your sketch must have labelled axes and show a gradual increase in the ionization energy for the first six electrons and a much sharper increase for the seventh electron (which is lost from the 3p sublevel). You may also show a slightly sharper increase in the ionization energy for the third electron (as the first two electrons are lost from the 4s sublevel while the third electron is lost from the 3d sublevel), but this is not required.

13 The periodic table—the transition metals (AHL)

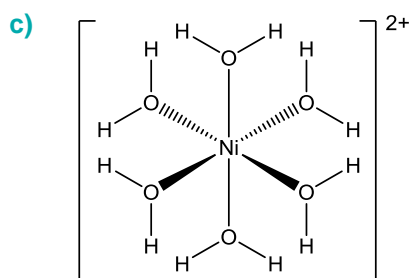
- 3–. Note that the answer "–3" is not acceptable.
 - +3. Note that the answer "3+" is not acceptable.
 - Octahedral.
 - Each CN^- ligand donates an electron pair to an empty d orbital of the central ion, Cr^{3+} , and thus forms a coordinate bond. Coordinate bonds are covalent by nature, but both electrons in their shared electron pairs originate from the same atom.
 - Paramagnetic, as it contains unpaired electrons (five in 3d sublevel and one in 4s sublevel).

Note that the presence of unpaired electrons in atomic chromium follows from its orbital diagram:

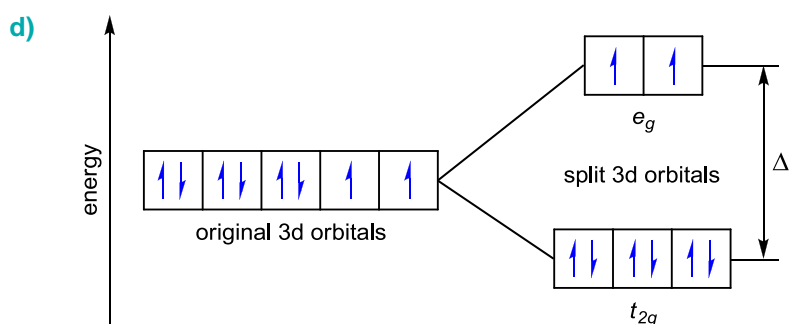


However, the diagram is not required in this question.

- According to the Lewis theory of acids and bases, this is a neutralization reaction. The Lewis base, H_2O , donates a lone electron pair on the oxygen atom to the empty electron orbital of the Ni^{2+} ion. By accepting an electron pair, the Ni^{2+} ion acts as a Lewis acid.
 - Coordinate bonding. Note that the term "dative bond" is obsolete.



Note that the three-dimensional structure is not required, so all coordinate bonds may be drawn as straight lines or arrows. The water molecules may be shown as "H₂O" or "OH₂", but the coordinate bonds should originate from O atoms, not from H atoms. The square brackets and the ionic charge (2+) are required for the mark.



Only the relative positions of the original and split orbitals are required. The orbitals can be represented as boxes or horizontal lines. The energy axis and all labels are optional.

- e) This complex is paramagnetic, as the central ion has two unpaired electrons in the e_g orbitals, as shown in part d).

14 Chemical bonding and structure (AHL)

- The correct answer is **A**. Statement III is incorrect, as the two p orbitals that form a π bond must have the same orientation.
- The correct answer is **B**. In carbon dioxide, CO₂, both carbon–oxygen bonds are double. In ethanoic acid, CH₃COOH, one carbon–oxygen bond is double while another is single. In carbonate anion, CO₃²⁻, one electron pair is delocalized, so all three carbon–oxygen bonds are identical (intermediate between single and double bonds).
- In structure **A**, both C and S atoms have zero formal charges, so $\Delta FC = 0$. In structure **B**, the formal charges of C and S atoms are 2– and 2+, respectively, so $\Delta FC = 4$. Therefore, structure **A** is preferred, as it has the lowest ΔFC value.

4.

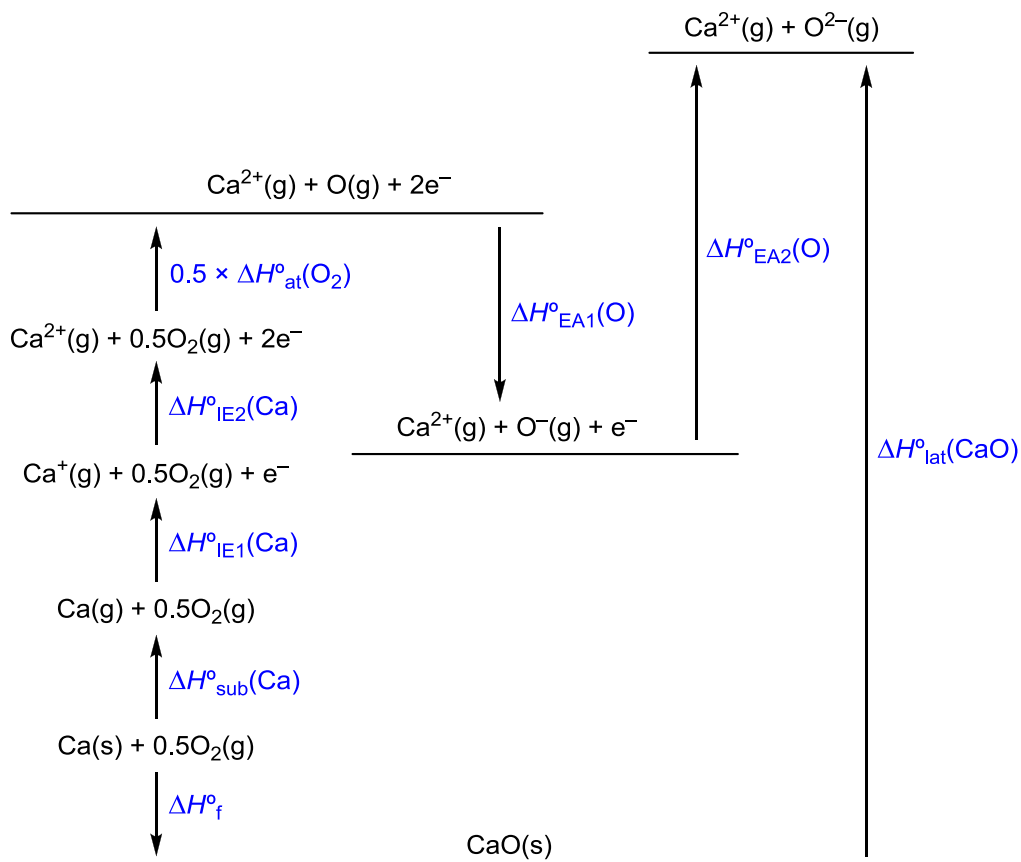
Species	Lewis (electron dot) structure	Electron domain geometry	Molecular geometry	Bond angles
$[\text{IBr}_4]^-$		octahedral	square planar (AB_4E_2)	90°
$[\text{IF}_4]^+$		trigonal bipyramidal	see-saw (AB_4E)	less than 90° ($\text{F}_a\text{--I--F}_e$) and less than 120° ($\text{F}_e\text{--I--F}_e$)

F_a = axial fluorine, F_e = equatorial fluorine

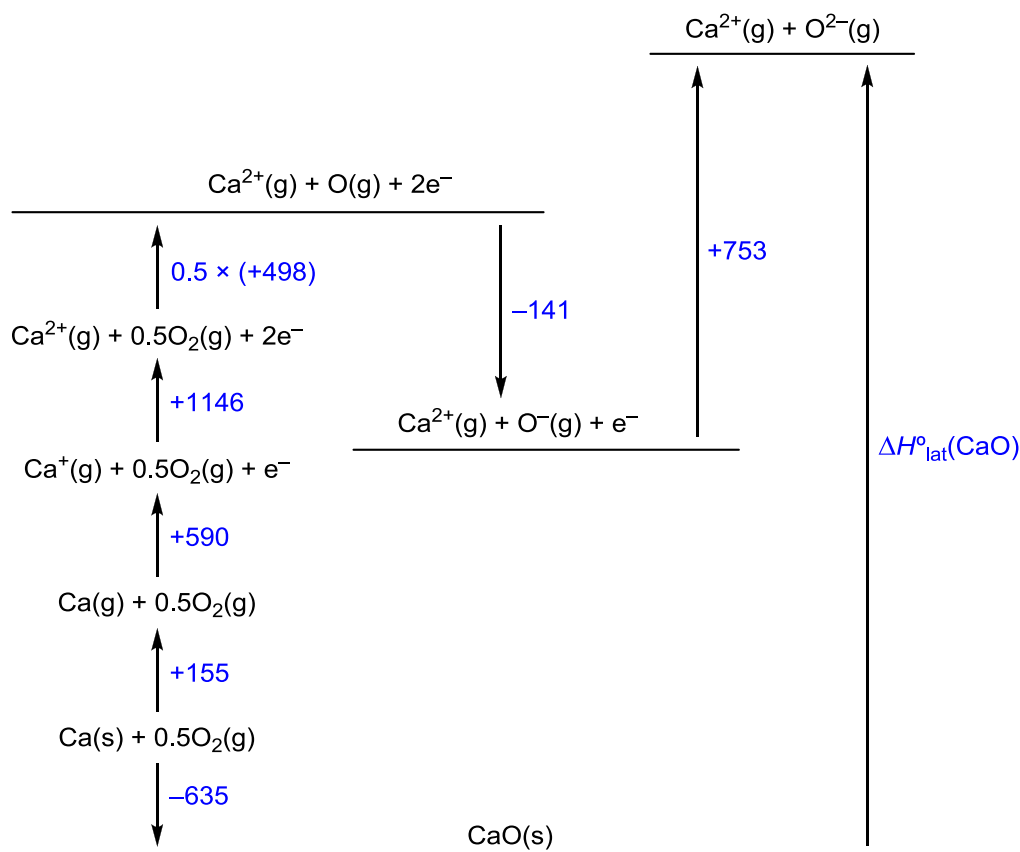
5. The correct answer is **C**. Both carbon atoms that form a double bond with each other have sp^2 hybridization.

15 Energetics/thermochemistry (AHL)

1. a) $\text{Ca(s)} + 0.5\text{O}_2(\text{g}) \rightarrow \text{CaO(s)}$
b)



- c) It is convenient to replace the enthalpies in the Born–Haber cycle from part (b) with their numerical values in kJ mol^{-1} :



Note that $\Delta H^\circ_{\text{at}}(\text{O}_2)$ is equal to $\text{BE}(\text{O}=\text{O})$, which is given in section 11 of the data booklet. The values of $\Delta H^\circ_{\text{IE1}}(\text{Ca})$, $\Delta H^\circ_{\text{EA1}}(\text{O})$ and $\Delta H^\circ_{\text{EA2}}(\text{O})$ are given in section 8 of the data booklet.

According to the diagram, $\Delta H^\circ_{\text{lat}}(\text{CaO}) = -(-635) + 155 + 590 + 1146 + 0.5 \times 498 + (-141) + 753 = +3387 \text{ kJ mol}^{-1}$. This answer is very close to the actual lattice enthalpy of calcium oxide ($+3401 \text{ kJ mol}^{-1}$), which is given in section 18 of the data booklet.

2. $\text{MgO} > \text{SrO} > \text{KF} > \text{KI}$.
Note that the lattice enthalpy increases with ionic charge and decreases with ionic radius.
3. The correct answer is **A**, as the number of gaseous species in the first reaction increases. In all other cases the entropy decreases.
4.
 - a) $\Delta S^\circ = 106.5 - 38.1 - 256.8 = -188.4 \text{ J K}^{-1}$
 - b)
 - i) $\Delta H^\circ = -1434.5 - (-634.9) - (-395.7) = -403.9 \text{ kJ}$
 - ii) Since $\Delta H^\circ < 0$, the reaction is exothermic.
 - c)
 - i) $\Delta S^\circ = -188.4 \text{ J K}^{-1} = -0.1884 \text{ kJ K}^{-1}$
 $\Delta G^\circ = -403.9 - 298 \times (-0.1884) \approx -347.8 \text{ kJ}$
 - ii) Since $\Delta G^\circ < 0$, the reaction is spontaneous.

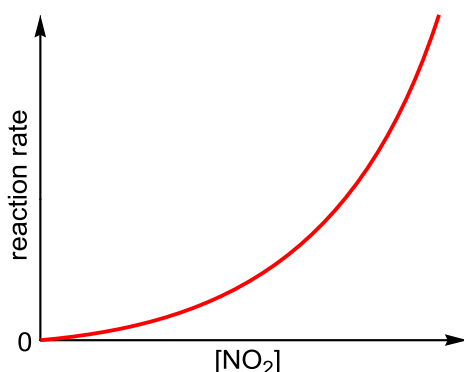
16 Chemical kinetics (AHL)

1. When $[F_2]$ increases 1.5 times, from 0.10 to 0.15 mol dm^{-3} , the rate also increases 1.5 times, from 1.2×10^{-3} to $1.8 \times 10^{-3} \text{ mol dm}^{-3} \text{ min}^{-1}$, so the reaction order in F_2 is 1. When $[ClO_2]$ increases three times, from 0.10 to 0.30 mol dm^{-3} , the rate also increases three times, from 1.2×10^{-3} to $3.6 \times 10^{-3} \text{ mol dm}^{-3} \text{ min}^{-1}$, so the reaction order in ClO_2 is also 1. Therefore, the overall reaction order is $1 + 1 = 2$, and the correct answer is **B**.

Note that the reaction order cannot be deduced from the stoichiometric coefficients in the equation.

2. a) $\text{rate} = k[NO_2]^2$. The answer " $\text{rate} = k[NO_2]^2[CO]^0$ " would also be accepted, although it is a good practice to exclude redundant factors from rate equations.
- b) The most common units for the reaction rate and concentration are $\text{mol dm}^{-3} \text{ s}^{-1}$ and mol dm^{-3} , so:

$$\text{mol dm}^{-3} \text{ s}^{-1} = (k)(\text{mol dm}^{-3})^2 = (k) \text{ mol}^2 \text{ dm}^{-6}$$
Therefore, the units for k are $\text{dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$
- c) If the second step were the RDS, then the reaction rate would depend on $[CO]$, which is not the case. Therefore, step 1 is the RDS.
- d) This is a second-order reaction, so the sketch will look as follows:



To score the full mark, both axes must be labelled, and the curve must begin at the origin.

- e) A catalyst will alter the reaction mechanism and introduce a new RDS with a lower activation energy, E_a .
3. a) According to section 1 of the data booklet, $\ln \frac{k_1}{k_2} = \frac{E_a}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$. Therefore:
 $T_1 = 25 + 273 = 298 \text{ K}$
 $T_2 = 45 + 273 = 318 \text{ K}$

$$\frac{k_2}{k_1} = \frac{v_2}{v_1}, \text{ so } \ln \frac{k_2}{k_1} = \ln \frac{1}{7.8} \approx -2.05$$

$$-2.05 = \frac{E_a}{8.31 \text{ J K}^{-1} \text{ mol}^{-1}} \left(\frac{1}{318 \text{ K}} - \frac{1}{298 \text{ K}} \right)$$

$$E_a \approx 80700 \text{ J mol}^{-1} = 80.7 \text{ kJ mol}^{-1}$$
- b) First, we need to determine the k value for this reaction at a certain temperature, T . Using the E_a value from part a), we can solve the Arrhenius equation and find the value of A . The Arrhenius equation and the value of R are given in sections 1 and 2, respectively, of the data booklet.

17 Equilibrium (AHL)

1. To produce 0.25 mol of $Z(g)$, 0.5 mol of X and 0.25 mol of Y must be consumed. Therefore:

	$2X(g) + Y(g) \rightleftharpoons Z(g)$		
$n_{\text{initial, mol}}$	1	2	0
$\Delta n, \text{ mol}$	-0.5	-0.25	+0.25
$n_{\text{final, mol}}$	0.5	1.75	0.25

Since $V = 1 \text{ dm}^3$, the amounts of all substances in mol are numerically equal to their concentrations in mol dm^{-3} . Therefore:

$$K_c = \frac{[Z]}{[X]^2[Y]} = \frac{0.25}{(0.5)^2 \times 1.75} \approx 0.57$$

Thus, the correct answer is **C**.

2. a) $\Delta G^\circ = -RT \ln K_c$, so $\ln K_c = \frac{-25200}{8.31 \times 923} \approx -3.285$ and $K_c = e^{-(-3.285)} \approx 26.7$.

Note that the temperature is expressed in kelvins ($650 + 273 = 923 \text{ K}$) and the Gibbs free energy in joules ($25.2 \text{ kJ} = 25200 \text{ J}$).

- b) When $Q = K_c$, the system is at equilibrium, so neither the forward nor the reverse reaction is favoured. Therefore, $\Delta G = 0$.

Note that we are talking about ΔG , not ΔG° , as at equilibrium the concentrations of reacting species may differ from their standard concentrations (1 mol dm^{-3}). In the general case, the ΔG° value for a reaction is nonzero even when the equilibrium is reached.

18 Acid and bases (AHL)

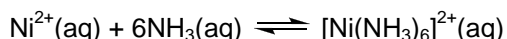
1. The correct answer is **C**, as the resulting solution will contain a conjugate acid–base pair, $\text{NH}_4^+(\text{aq})$ and $\text{NH}_3(\text{aq})$, in which both components are weak electrolytes:

	$\text{NH}_3(\text{aq}) + \text{H}^+(\text{aq}) \rightleftharpoons \text{NH}_4^+(\text{aq})$		
	conjugate base		conjugate acid
$n_{\text{initial, mol}}$	0.003	0.002	0
$\Delta n, \text{ mol}$	-0.002	-0.002	+0.002
$n_{\text{final, mol}}$	0.001	0	0.002

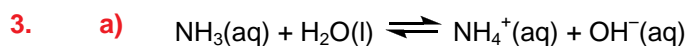
Note that $n(\text{NH}_3) = 0.03 \text{ dm}^3 \times 0.10 \text{ mol dm}^{-3} = 0.003 \text{ mol dm}^{-3}$ and $n(\text{H}^+) = 2 \times n(\text{H}_2\text{SO}_4) = 2 \times 0.01 \text{ dm}^3 \times 0.10 \text{ mol dm}^{-3} = 0.002 \text{ mol dm}^{-3}$.

All other combinations of electrolytes will not form acid–base buffers. Mixture **A** contains only acids while mixtures **B** and **D** contain no weak electrolytes other than water.

2. The formation of the complex ion, $[\text{Ni}(\text{NH}_3)_6]^{2+}(\text{aq})$, can be represented as follows:



In this reaction, $\text{Ni}^{2+}(\text{aq})$ acts as a Lewis acid by accepting lone electron pairs from the ligands, $\text{NH}_3(\text{aq})$. In turn, the ligands act as Lewis bases by donating their lone electron pairs to the nickel(II) ion. Therefore, in terms of the Lewis theory, this reaction can be classified as a neutralisation reaction.



According to section 21 of the data booklet, $\text{p}K_b(\text{NH}_3) = 4.75$, therefore:

$$K_b(\text{NH}_3) = 10^{-4.75} \approx 1.78 \times 10^{-5}$$

$$[\text{OH}^-] = \sqrt{K_b \times c} = \sqrt{1.78 \times 10^{-5} \times 0.10} \approx 1.33 \times 10^{-3} \text{ mol dm}^{-3}$$

$$\text{pOH} = -\log(1.33 \times 10^{-3}) \approx 2.88$$

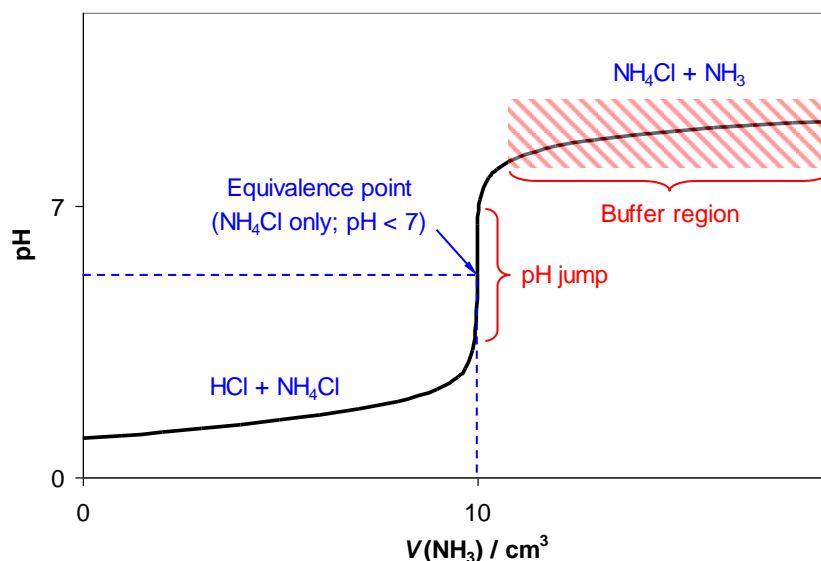
$$\text{pH} = 14 - \text{pOH} = 14 - 2.88 = 11.12$$

Alternative solution:

$$\text{pOH} = 0.5(\text{p}K_b - \log c) = 0.5(4.75 - \log(0.10)) \approx 2.88$$

$$\text{pH} = 14 - 2.88 = 11.12$$

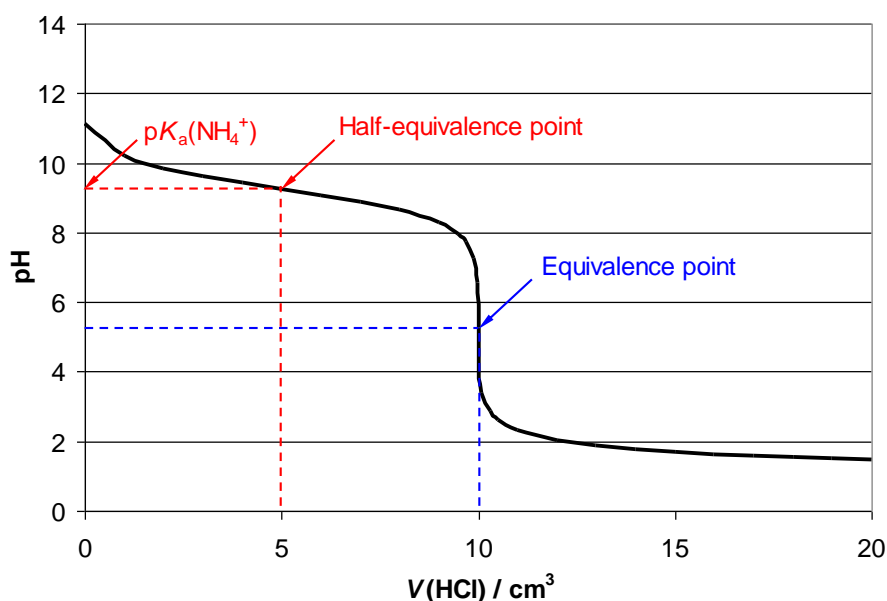
b) A fully annotated sketch is shown below.



To score the full mark, your sketch must show the labelled axes, the equivalence point at $\text{pH} < 7$ and the buffer region. All other labels are optional.

- c) Any acid–base indicator with a $\text{p}K_a < 7$ can be used, so the acceptable answers are "methyl orange", "bromophenol blue", "bromocresol green" and "methyl red".
- d) The overall shape will change very little, except that the left hand side of the curve will be one pH unit higher, the equivalence point will be a fraction of a pH unit higher, and the pH jump will become slightly less pronounced.
- e) The curve shown in figure 18.3.3 is more suitable, as it allows you to determine the position of the half-equivalence point even if the concentration of the analysed ammonia solution is unknown. In contrast, finding the half-equivalence point on the curve in part (b) is more difficult, as it requires additional calculations.

- f) To determine the pK_b of ammonia, you need to find the equivalence point, divide the equivalence volume of HCl(aq) by two and mark the half-equivalence point. The horizontal line from the half-equivalence point to the y -axis will show the pK_a of the conjugate acid, $\text{NH}_4^+(\text{aq})$, as shown below.



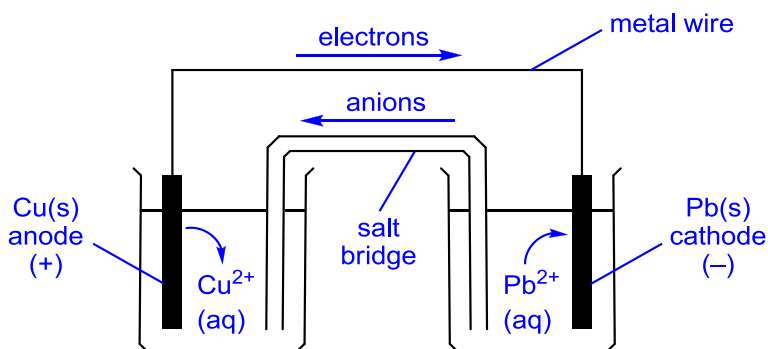
The pK_b of the conjugate base, $\text{NH}_3(\text{aq})$, can be calculated as follows:
 $pK_b(\text{NH}_3) = 14 - pK_a(\text{NH}_4^+)$

In a typical IB exam paper, part (f) would be a three-mark question. The first mark would be awarded for mentioning half-equivalence point, the second for showing how to find pK_a and the third for the relationship between pK_a and pK_b . Thus, the one-line answer "at half-equivalence $\text{pH} = pK_a$ and $pK_b = 14 - pK_a$ " will score all three marks.

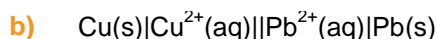
- g) Any one of the following two techniques can be used: conductometric titration (electrical conductivity measurement) and thermometric titration (temperature measurement). Note that the answers like "conductivity probe" or "digital thermometer" will not score the mark, as these are the names of laboratory equipment, not techniques. At the same time, the answers "titration with a conductivity probe" and "titration with a digital thermometer" will be accepted, as they mention the technique (titration).

19 Redox processes (AHL)

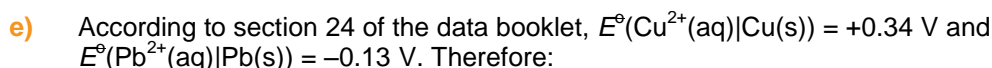
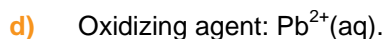
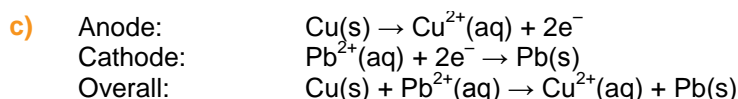
1. a)



The electrodes can be connected with a metal wire either directly or through a voltmeter (or any other device, such as a light bulb). In addition to the flow of anions, the flow of cations through the salt bridge (from left to right) can also be shown.

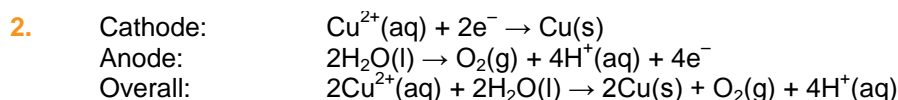


Note that the cathode must be drawn on the right-hand side.



$$E^\ominus_{\text{cell}} = +0.34 \text{ V} - (-0.13 \text{ V}) = +0.47 \text{ V}.$$

Note that the overall process in a voltaic cell is always spontaneous, so the E^\ominus_{cell} must be positive.



According to the overall equation, the mole ratio of Cu(s) to $\text{O}_2(\text{g})$ is 2 : 1. Therefore:

$$n(\text{Cu(s)}) = 5.34 \text{ g} / 63.55 \text{ g mol}^{-1} \approx 0.0840 \text{ mol}$$

$$n(\text{O}_2(\text{g})) = 0.0840 \text{ mol} / 2 = 0.0420 \text{ mol}$$

$$V(\text{O}_2(\text{g})) = 0.0420 \text{ mol} \times 22.7 \text{ dm}^3 \text{ mol}^{-1} \approx 0.953 \text{ dm}^3 = 9.53 \times 10^{-4} \text{ m}^3$$

20 Organic chemistry (AHL)

1. The correct answer is **B**, as aldehydes can be both reduced and oxidised. Alcohols (answers **A** and **C**) cannot be reduced while ketones (answer **D**) cannot be oxidised by the given reagents.

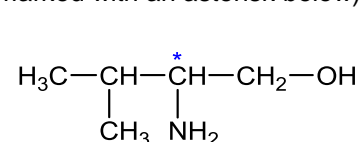
2. a) Ethane is an alkane while ethanal is an aldehyde. According to figure 20.2.1, an aldehyde can be synthesised from an alkane as follows:

alkane \rightarrow halogenoalkane \rightarrow alcohol \rightarrow aldehyde

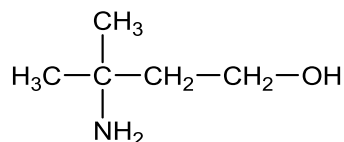
Step	Equation	Reagents and conditions	Reaction type
1	$\text{CH}_3\text{CH}_3 + \text{Br}_2 \rightarrow \text{CH}_3\text{CH}_2\text{Br} + \text{HBr}$	bromine or chlorine, $h\nu$ (light)	radical substitution (S_R)
2	$\text{CH}_3\text{CH}_2\text{Br} + \text{OH}^- \rightarrow \text{CH}_3\text{CH}_2\text{OH} + \text{Br}^-$	dilute aqueous NaOH	nucleophilic substitution (S_N)
3	$\text{CH}_3\text{CH}_2\text{OH} \xrightarrow{[\text{O}]} \text{CH}_3\text{CHO}$	distillation with acidified potassium dichromate	oxidation

- b) See figure 20.1.2 in the main text.

3. a) Only 2-amino-3-methylbutan-1-ol can show optical activity, as it has a chiral carbon atom (marked with an asterisk below).

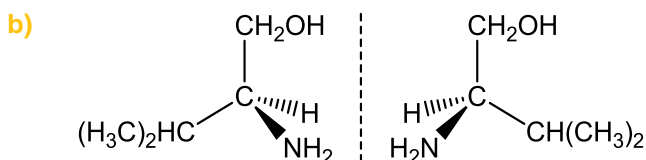


2-amino-3-methylbutan-1-ol



3-amino-3-methylbutan-1-ol

Remember that a chiral carbon atom must have four different substituents.



To score the full mark, your structures must satisfy the following criteria:

- have the chiral carbon atom at the centre of each structure (asterisks are not required);
 - show the three-dimensional orientation of the four substituents at each chiral centre;
 - be mirror images of each other.
- c) They can be distinguished by polarimetry. When placed inside the polarimeter (as pure liquids or solutions), the two enantiomers will rotate the plane of plane-polarised light in opposite directions. The absolute angles of rotation will be the same for pure enantiomers or their solutions of equal concentrations. The optically inactive compound, 3-amino-3-methylbutan-1-ol, will not rotate the plane of plane-polarised light.

21 Measurement and analysis (AHL)

1.

Proton(s)	δ , ppm	Relative integration	Splitting pattern
CH ₃	0.9–1.0	3	triplet
CH ₂	2.2–2.7	2	quintet*
CHO	9.4–10	1	triplet

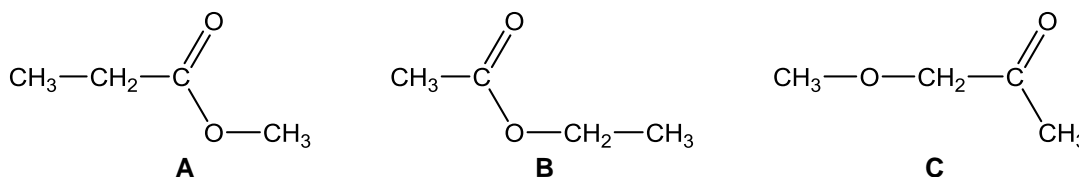
* The actual splitting will be a doublet of quartets, as the signal of the CH₂ protons will split independently on the three adjacent CH₃ protons (quartet) and one adjacent CHO proton (doublet). Since the IB syllabus does not cover complex splitting patterns, both answers (quintet or doublet of quartets) will be equally acceptable in examination papers.

2. $\text{IHD}(\text{C}_4\text{H}_8\text{O}_2) = 0.5(2 \times 4 + 2 - 8) = 1$. Therefore, compound X contains either one double bond or one ring.

The IR spectrum of X shows a strong absorption around 1750 cm^{-1} . According to section 26 of the data booklet, this suggests the presence of a C=O bond (carbonyl group). At the same time, the absorption around 2950 cm^{-1} is relatively strong but not very broad, so compound X contains C–H bonds but no O–H bonds.

The ^1H NMR spectrum of X shows three signals with relative integrations of 3 : 2 : 3. Therefore, compound X contains two CH₃ groups and one CH₂ group. These three groups contain three carbon atoms and eight hydrogen atoms, so the fourth carbon atom of compound X has no attached protons.

We have now identified five fragments of compound X: two CH₃ groups, one CH₂ group, one C=O group and the remaining O atom. There are only three possible ways to connect all these fragments together:

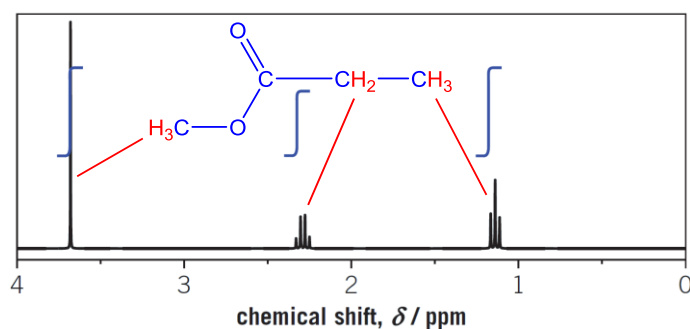
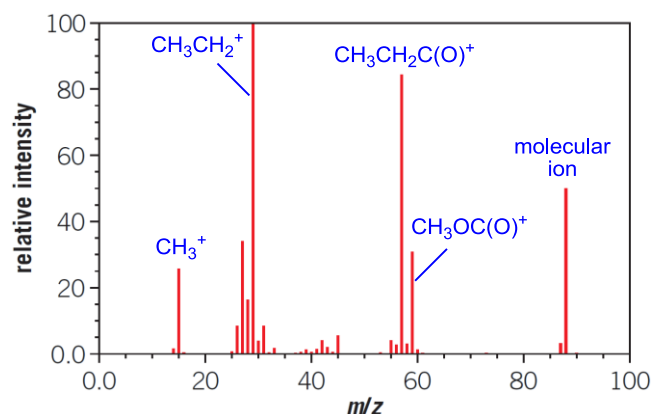
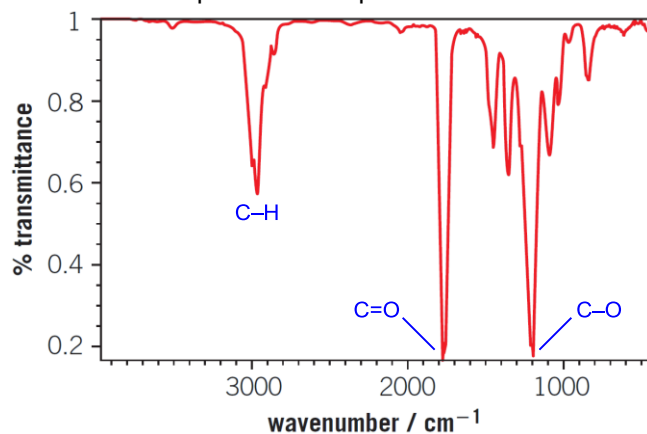


Structure **C** can be dismissed immediately, as it would produce three singlets in the ^1H NMR spectrum while we have a singlet (one of the CH_3 groups), a quartet (the CH_2 group) and a triplet (another CH_3 group). Therefore, we have to choose between structures **A** and **B** only.

According to section 27 of the data booklet, the protons of the CH_2 group in structure **A** would have a chemical shift of 2.0–2.5 ppm while in structure **B** they would have a chemical shift of 3.7–4.8 ppm. In compound X, the quartet of the CH_2 protons appears at approximately 2.3 ppm, which corresponds to structure **A**. Similarly, the singlet around 3.7 ppm in compound X falls into the predicted range for the OCH_3 singlet in structure **A** (3.7–4.8 ppm) while the $\text{CH}_3\text{C}(\text{O})$ group in structure **B** would produce a singlet at 2.0–2.5 ppm. Therefore, compound X has structure **A**.

The analysis of the mass spectroscopy data leads to the same conclusion. Structure **A** would produce peaks of the $\text{CH}_3\text{CH}_2\text{C}(\text{O})^+$ and $\text{CH}_3\text{OC}(\text{O})^+$ fragments at $m/z = 57$ and $m/z = 59$, respectively, both of which are present in the actual mass spectrum of X. In contrast, structure **B** would produce peaks of the $\text{CH}_3\text{C}(\text{O})^+$ and $\text{CH}_3\text{CH}_2\text{OC}(\text{O})^+$ fragments at $m/z = 43$ and $m/z = 73$, respectively, but these peaks are absent in the mass spectrum of X. Therefore, structure **A** is correct.

The annotated spectra of compound X are shown below.



22 Data-based and practical questions (Section A)

Part 1

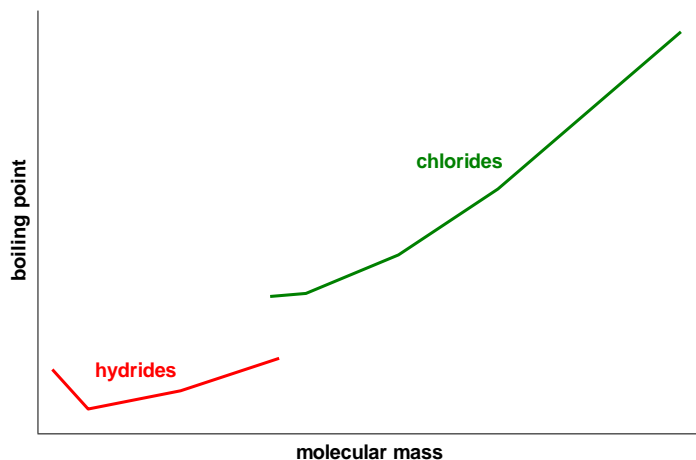
1. a) i) Yes, there is a positive correlation: as the percentage of saturated triglycerides in the oil increases, the melting point also increases.
- ii) No, there is no obvious correlation: as the percentage of monosaturated triglycerides in the oil increases, the melting point changes randomly. For example, the oils with the lowest ($-24\text{ }^{\circ}\text{C}$) and the second-highest ($+18\text{ }^{\circ}\text{C}$) melting points have similar percentages of monounsaturated triglycerides (16 and 15%, respectively). At the same time, the oil with the highest percentage of monounsaturated triglycerides (75%) has a mid-range melting point ($-8\text{ }^{\circ}\text{C}$).
- b) It should be somewhere between -5 and $+18\text{ }^{\circ}\text{C}$; the mid-point of this range is $\approx 7\text{ }^{\circ}\text{C}$.
- c) The molecules of triglycerides are held together by weak London dispersion forces. The strength of these forces depends not only on the saturation/unsaturation of fatty acid residues but also on their length. Since the actual melting point of palm oil is higher than expected, the fatty acid residues in that oil are likely to have longer hydrocarbon chains than the residues in other oils. Longer hydrocarbon chains contain more electrons and thus experience stronger dispersion forces of attraction. The stronger the intermolecular forces, the higher the melting point.

The essential point in this question is the correlation between the chain length and the strength of London dispersion forces. The short answer "palm oil has longer hydrocarbon chains and thus stronger dispersion forces" would score the full mark.

- d) i) Palmitoleic: monounsaturated (one $\text{C}=\text{C}$ bond); linoleic: polyunsaturated (two $\text{C}=\text{C}$ bonds); arachidic: saturated (no $\text{C}=\text{C}$ bonds). The number of $\text{C}=\text{C}$ bonds can be determined using the index of hydrogen deficiency (IHD; see topic 11.3).
- ii) According to table 22.1.2, the melting points of oils increase with their degree of saturation. We can expect a similar trend for individual fatty acids, so the saturated arachidic acid is likely to have the highest melting point.

Note that arachidic acid has the longest hydrocarbon chain, which also suggests that its melting point will be the highest. However, your answer must be based on the data from table 22.1.2, so a reference to saturation is essential for the mark.

2. a) NCl_3 , PCl_3 and AsCl_3 . All three compounds have melting points below 298 K and boiling points above 298 K.
- b)



To score the full mark, your sketch must contain the labelled axes and the two labelled curves of approximately the same shapes as shown above (not necessarily drawn to scale).

- c) Both curves show a positive correlation: as the molecular mass increases, the boiling point also increases. The only exception is ammonia, NH_3 , which has a higher boiling point than its heavier analogue, PH_3 . Molecules of ammonia form hydrogen bonds with each other. Breaking these bonds requires extra energy, so ammonia boils at a higher temperature than expected.
- d) The central atom in all molecules from table 22.1.3 has four electron domains in a tetrahedral arrangement. One of these domains is a lone electron pair while the other three are bonding electron pairs. The dipoles created by the lone pair and the bonding pairs do not cancel one another, so the whole molecule has a net dipole moment.
- e) i) For hydrides, the molecular dipole moment decreases as the bond length increases (negative correlation) and bond angle decreases (positive correlation). For chlorides, the molecular dipole moment increases as the bond length increases (positive correlation) and bond angle decreases (negative correlation).
- ii) According to section 6 of the data booklet, the electronegativity of hydrogen (2.2) is lower than that of nitrogen (3.2), so the vector sum of dipoles of covalent bonds in NH_3 points in the same direction as the dipole of the lone electron pair (figure A). The electronegativities of phosphorus and arsenic are identical to that of hydrogen, so the molecular dipoles in PH_3 and AsH_3 are produced by lone electron pairs only. Finally, antimony and bismuth are less electronegative than hydrogen, so the dipoles of covalent bonds and the lone electron pairs in SbH_3 and BiH_3 point in opposite directions.

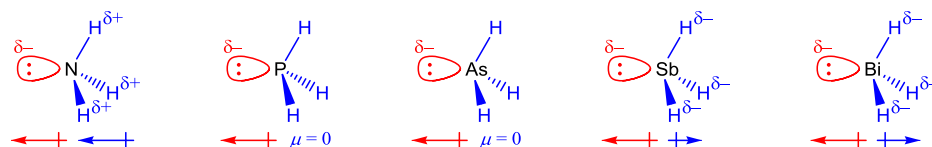


Figure A. Dipole moments of hydrides of group 15 elements

Since hydrogen has a small covalent radius, the bond dipoles in hydrides are also small, so they cancel the dipole of the lone electron pair only partially. This effect becomes more noticeable when the size of the central atom increases and its electronegativity decreases, so the net dipole moment of hydrides decreases from N to Bi.

In chlorides of group 15 elements, the dipoles of covalent bonds and the dipole of the lone electron pair always point in opposite directions (figure B). However, the vector sum of bond dipoles is greater than the dipole of the lone pair. As the electronegativity of the central atom decreases, the vector sum of bond dipoles also increases, and so does the net dipole moment of the molecule.

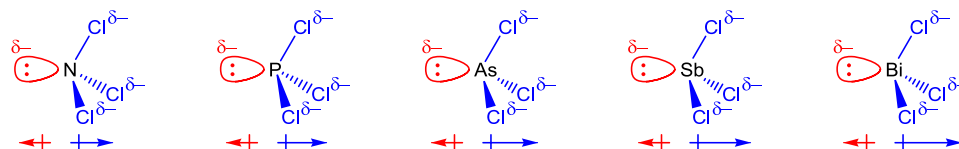


Figure B. Dipole moments of chlorides of group 15 elements

In a typical examination paper, the marks for this question will be awarded for the following suggestions:

- the dipoles of covalent bonds and the lone electron pair can point in opposite direction / cancel each other;
- the vector sum of bond dipoles in hydrides has a smaller magnitude than the dipole of the lone electron pair;
- the vector sum of bond dipoles in chlorides has a larger magnitude than the dipole of the lone electron pair;
- bond dipoles increase along with the bond length and the difference in electronegativity.

All marks can also be scored by clearly annotated diagrams.

Part 2

1. a) i) Reaction **B** is faster than reaction **A**, so iodide ions consumed in the first reaction are almost immediately reformed in the second reaction.

ii) $n(\text{H}_2\text{O}_2) = 0.0200 \text{ dm}^3 \times 0.500 \text{ mol dm}^{-3} = 0.0100 \text{ mol}$

$n(\text{S}_2\text{O}_3^{2-}) = n(\text{Na}_2\text{S}_2\text{O}_3) = 0.0200 \text{ dm}^3 \times 0.0100 \text{ mol dm}^{-3} = 0.000200 \text{ mol}$

Since H_2O_2 is in a large excess, only a small proportion of H_2O_2 will react with $\text{S}_2\text{O}_3^{2-}$, so its concentration will decrease insignificantly.

- iii) Relative uncertainty of the amount of H_2SO_4 :

$$\frac{0.1 \text{ cm}^3}{20.0 \text{ cm}^3} = 0.005$$

Absolute uncertainty of the volume of the reaction mixture:

$$\sqrt{(0.1 \text{ cm}^3)^2 \times 5} \approx 0.2 \text{ cm}^3$$

Total volume of the reaction mixture:

$$50.0 \text{ cm}^3 + 20.0 \text{ cm}^3 + 20.0 \text{ cm}^3 + 20.0 \text{ cm}^3 + 5.0 \text{ cm}^3 = 115 \text{ cm}^3$$

Relative uncertainty of the volume of the reaction mixture:

$$\frac{0.2 \text{ cm}^3}{115.0 \text{ cm}^3} \approx 0.002$$

Percentage uncertainty of the concentration of H_2SO_4 :

$$\sqrt{(0.005)^2 + (0.002)^2} \times 100\% \approx 0.5\%$$

- iv) Any **two** of the following are required for the mark:

- temperature of the solutions;
- rate and order of addition of the solutions;
- rate and method of stirring of the reaction mixture;

human limitations (the reaction time of the stopwatch operator).

- v) Each of the first three factors from part (iv) can produce both random and systematic errors. For example, small changes in the ambient temperature during the experiment will affect the reaction time randomly and unpredictably. However, storing the solutions near a source of heat will consistently increase the reaction rate and thus cause a systematic error. Similarly, the rates of addition and stirring can vary between experiments either randomly or systematically (for example, if the reaction mixture was stirred with a glass rod in one experiment and with a magnetic stirrer in another experiment).

Human limitations typically produce random errors. However, a stopwatch operator with a slow reaction time may consistently press the button too late and thus introduce a systematic error.

- b) In a typical examination paper, this question will carry two or three marks. To achieve the maximum score, you will need to state any two or three of the following:
- wear laboratory coat and safety glasses;
 - weigh solid potassium iodide using an analytical balance;
 - dissolve potassium iodide in less than 50 cm^3 of deionised water;
 - transfer the solution to a 50 cm^3 volumetric flask;
 - add deionised water to the graduation mark, stopper the flask and turn it over several times to stir the solution thoroughly.

Another acceptable procedure may involve the dilution of a standard concentrated solution of potassium iodide using a volumetric pipette or burette and a volumetric flask.

- c) In the first experiment, the solution will turn blue-black almost immediately, as there will be no thiosulfate ions to delay the formation of molecular iodine. In the second experiment, the colour change will occur later than expected, as extra sodium thiosulfate will take more time to react completely.
2. a) By weighing the spirit burner with ethanol immediately after extinguishing the flame and subtracting the final mass of the burner from its initial mass.
- b) Any **two** of the following assumptions will score the full mark:
- no heat was lost to the environment / all heat produced by the combustion of ethanol was absorbed by the water in the flask;
 - the heat capacities of the flask and thermometer were negligible;
 - the evaporation of water from the flask was negligible;
 - the combustion of ethanol was complete.
- c) Heat loss to the environment. Other factors listed in part b) typically produce much smaller errors.
- d) This hypothesis is incorrect. The precision of the original balance was two decimal places (0.01 g), so even if the mass of burned ethanol was very small (let's say, 1.00 g), the absolute error of 0.01 g would produce a relative error of about 1%. Such error is insignificant when compared to the actual experimental error (about 50%) of the ΔH_c value. Therefore, the improvement that could be achieved by using a more precise analytical balance would be almost negligible.
- e) To reduce systematic errors, the student could do one or more of the following:
- install a draught screen around the apparatus (to reduce the heat loss to the environment);
 - use a flask or metal container (such as a tin can) with very thin walls (to reduce the heat capacity of the apparatus);
 - use a smaller thermometer (again, to reduce the heat capacity of the apparatus);
 - weigh the flask before and after the experiment (to determine the mass of evaporated water and take it into account when calculating the ΔH_c value);
 - adjust the wick to produce colourless flame and prevent soot deposition on the flask (to ensure complete combustion of ethanol).

There are many other possible adjustments, the most radical of which is the use of an analytical-grade calorimeter (which can measure ΔH_c values with a relative error of less than 1%).

Option A Materials

A1.1

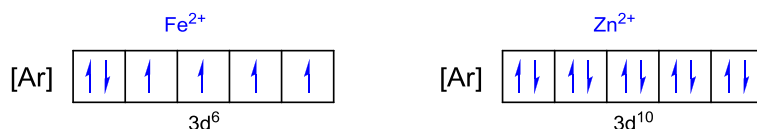
Species	$\Delta\chi$	$\bar{\chi}$	Bonding type	% ionic character
F ₂	0	4.0	non-polar covalent	0
KBr	2.2	1.9	ionic	60
PbBr ₂	1.2	2.4	polar covalent	33

A1.2

Alloys are usually homogeneous mixtures of two or more substances, at least one of which is a metal. Composites are always heterogeneous, and they may or may not contain a metal. The predominant type of bonding in an alloy is metallic while both the matrix and reinforcing phases in a composite can have any type of bonding.

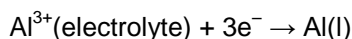
A1.3 Platinum is a d-block element. All d-block elements are metals due to the presence of only two s electrons in their outer energy level. The s electrons of all atoms in a platinum sample form a delocalized cloud that surrounds platinum cations. The electrostatic attraction between the electrons and cations produces strong metallic bonding. When a piece of platinum is pulled into a wire, the layers of platinum cations slide past one another without breaking the metallic bonding, so platinum metal is ductile.

A2.1 The orbital diagrams of Fe^{2+} and Zn^{2+} ions are shown below.



Fe^{2+} ions are paramagnetic, as they contain unpaired electrons in the 3d sublevel. In contrast, all electrons in Zn^{2+} ions are paired, so these ions are diamagnetic.

A2.2 $\text{Al}_2\text{O}_3(\text{l}) \rightarrow 2\text{Al}(\text{l}) + 1.5\text{O}_2(\text{g})$



$$n(\text{Al}) = \frac{2.000 \times 10^3 \text{ g}}{26.98 \text{ g mol}^{-1}} \approx 74.13 \text{ mol}$$

$$n(\text{e}^-) = 3 \times n(\text{Al}) = 3 \times 74.13 \text{ mol} = 222.4 \text{ mol}$$

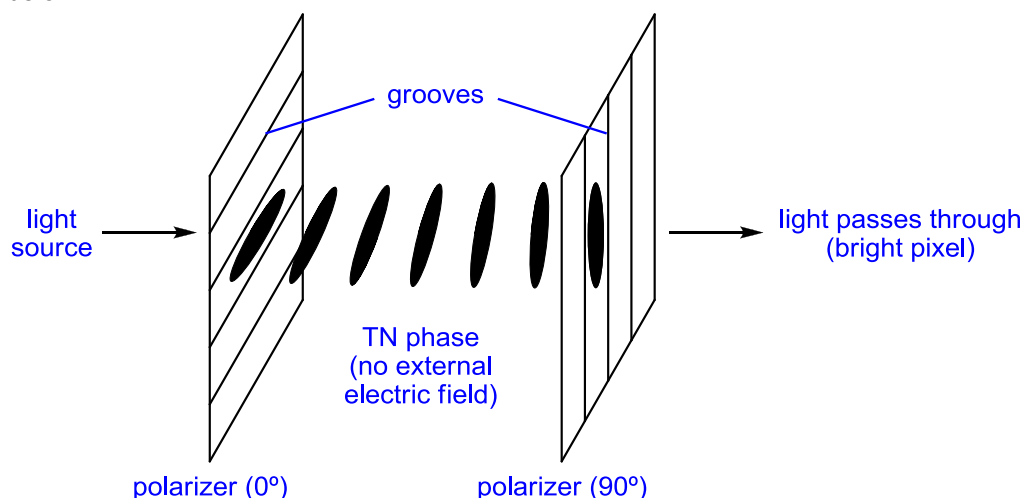
According to section 1 of the data booklet, $F = 9.65 \times 10^4 \text{ C mol}^{-1}$, so:

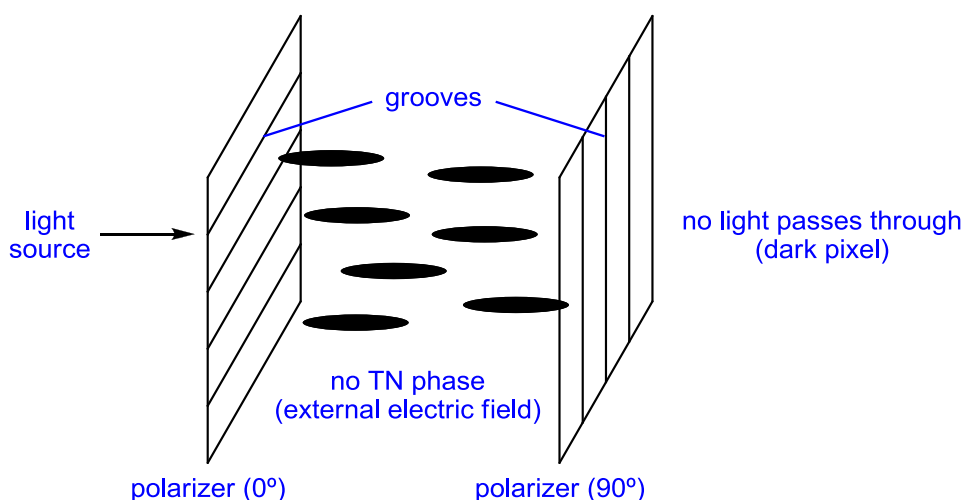
$$Q = 222.4 \text{ mol} \times 9.65 \times 10^4 \text{ C mol}^{-1} \approx 2.15 \times 10^7 \text{ C.}$$

A2.3 An alloy contains ions of different sizes, which form a less regular lattice than that of pure aluminium. The layers of cations in an irregular lattice do not slide past one another as easily as in pure aluminium, so an aluminium-based alloy is typically less malleable than pure aluminium.

A3.1 A homogeneous catalyst chemically combines with a reactant to form a reaction intermediate or an activated complex. This intermediate or complex then reacts with another reactant, forming the reaction product and releasing the catalyst. The activation energy of the slowest step in this two-step process is lower than the activation energy of the uncatalyzed reaction.

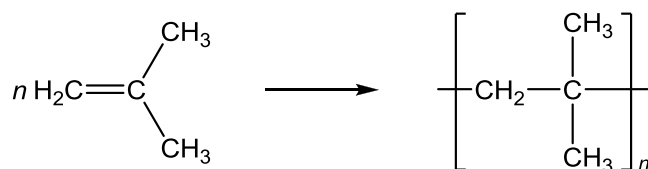
A4.1 The diagrams of a bright pixel (top) and a dark pixel (bottom) on a TN LCD display are shown below.





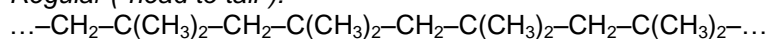
A4.2 Linear (rod-like) shape.

A5.1 a)

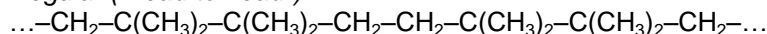


- b)** Thermoplastic (as it does not undergo any chemical changes when heated to a moderately high temperature).
- c)** The mutual orientation of repeating units in poly(2-methylpropene) can be regular or irregular, as shown below.

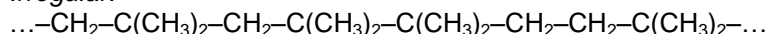
Regular ("head to tail"):



Regular ("head to head"):

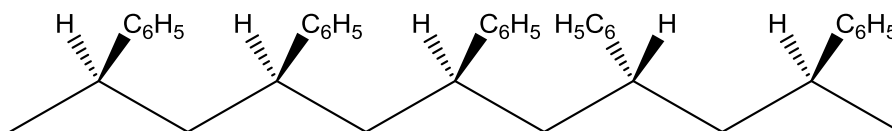


Irregular:



The regular and irregular polymer chains will pack together in different ways, so the intermolecular forces between these chains will differ in strength. As a result, the polymers will have different properties.

A5.2



A5.3 The molar masses of the reactants (ethanoyl chloride and methylamine) and the target product (*N*-methylethanamide) are 78.50, 31.07 and 73.11 g mol⁻¹, respectively. Therefore:

$$\text{atom economy} = \frac{73.11}{78.50 + 31.07} \times 100\% \approx 66.72\%$$

- A6.1 a)** Nanotechnology is the general name for various techniques that involve the manufacture and use of objects with dimensions from 1 to 100 nm.
- b)** Typical examples are microprocessors, LCD screens, nanocatalysts and surface coatings. Your answer can include any two of these or other examples.

- c) The two major issues are risks to human health and the environment.

The exposure of humans to nanoparticles through inhalation, ingestion or skin contact may cause various diseases and health conditions, such as asthma, fibrosis, gastrointestinal and neurological problems, systemic stress and inflammatory response, skin irritation and cancer. Nanocatalysts can cause systemic toxicity and accelerated aging.

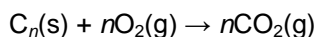
The release of nanoparticles to the environment can cause similar problems in animal and plant species. These problems can reduce the biodiversity of local and global ecosystems, decrease the efficiency of farming and increase the cost of food and other agricultural products.

- A6.2 a) Carbon nanotubes have giant covalent structure, where all carbon atoms have sp^2 hybridization. Each carbon atom forms three sigma-bonds with its neighbours, which requires three of its four valence electrons. The fourth valence electron becomes a part of the delocalized electron cloud that surrounds all carbon atoms of the nanotube. Because of that, the bond order of each covalent bond is approximately 1.33.

A carbon nanotube can also be described as a sheet of graphene rolled into a tube.

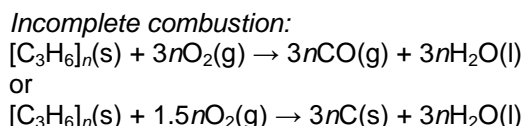
- b) Your answer should include any **two** of the following: high mechanical strength, high electrical conductivity, high thermal conductivity, high melting point and low density.

- c) All allotropes of carbon, including carbon nanotubes, are flammable:



Since CVD requires high temperatures, an attempt to use oxygen as a carrier gas would produce carbon dioxide instead of carbon nanotubes.

- A7.1 a) *Complete combustion:*
 $[C_3H_6]_n(s) + 4.5nO_2(g) \rightarrow 3nCO_2(g) + 3nH_2O(l)$



- b) A mixture of PVC and polypropene should not be incinerated because the incineration may produce toxic and ozone-depleting compounds, such as hydrogen chloride, phosgene and dioxins. Such mixture is also difficult to recycle, as chlorinated and non-chlorinated plastics have different properties.

- c) RICs provide information about the chemical composition and structure of plastics. The RICs allow you to choose the best possible procedure for the disposal or recycling of each type of plastic and thus minimize the cost and environmental impact of these processes.

- d) Recycling of plastics allows to save energy and raw materials (such as fossil fuels), reduce the cost of plastic-based products and minimize the environmental impact of the plastic waste. Recycling creates jobs and saves land (which otherwise would be used for landfills). Recycling of polymers is usually more expensive than recycling of paper and metals, but the initial high costs are compensated by long-term savings and environmental benefits.

A8.1 a) Your answer can include any **two** of the following:

Type 1 superconductors	Type 2 superconductors
lower critical temperature (T_c)	higher critical temperature (T_c)
sharp transition to superconductivity	gradual transition to superconductivity
have no mixed state	have mixed state
expel magnetic fields completely	partly allow magnetic fields to penetrate (in the mixed state)
have one critical magnetic field (B_c)	have two critical magnetic fields (B_{c1} and B_{c2})
usually pure metals	alloys, ceramics or composites

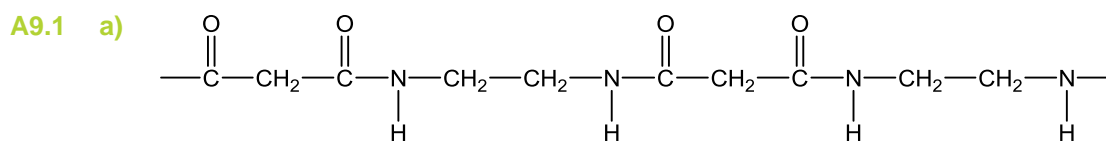
b) As an electron passes through a type 1 superconductor, it attracts the metal cations and thus deforms the lattice. This deformation creates a region of increased positive charge density. This region attracts another electron with a spin opposite to that of the first electron. The two electrons form a Cooper pair, which can travel through the lattice freely (without electrical resistance).

A8.2 $V(\text{cell}) = (352.4 \text{ pm})^3 \approx 4.376 \times 10^7 \text{ pm}^3 = 4.376 \times 10^{-23} \text{ cm}^3$

$$m(\text{cell}) = 4.376 \times 10^{-23} \text{ cm}^3 \times 8.908 \text{ g cm}^{-3} \approx 3.898 \times 10^{-22} \text{ g}$$

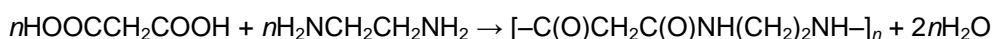
$$N(\text{atoms per cell}) = \frac{3.898 \times 10^{-22} \text{ g}}{58.69 \text{ g mol}^{-1}} \times 6.02 \times 10^{23} \text{ mol}^{-1} \approx 4$$

Therefore, nickel forms a face-centred lattice, as only this type of lattice has four atoms per unit cell.



b) H_2O

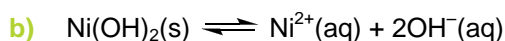
c) The polycondensation reaction can be represented as follows:



The molar masses of the reactants and the target product are 104.07, 60.12 and $128.15n \text{ g mol}^{-1}$, respectively. Therefore:

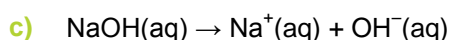
$$\text{atom economy} = \frac{128.15n}{104.07n + 60.12n} \times 100\% \approx 78.05\%$$

A10.1 a) $K_{sp} = [\text{Ni}^{2+}][\text{OH}^-]^2$



Let $[\text{Ni}^{2+}] = x \text{ mol dm}^{-3}$, then $[\text{OH}^-] = 2x \text{ mol dm}^{-3}$. According to section 32 of the data booklet, $K_{sp}(\text{Ni}(\text{OH})_2) = 5.48 \times 10^{-16}$, so:

$$\begin{aligned} x \times (2x)^2 &= 5.48 \times 10^{-16} \\ 4x^3 &= 5.48 \times 10^{-16} \\ x &\approx 5.16 \times 10^{-6} \text{ mol dm}^{-3} \end{aligned}$$



Since the solubility of $\text{Ni}(\text{OH})_2$ is very low, nearly all $\text{OH}^-(\text{aq})$ ions in the solution will be produced by the dissociation of sodium hydroxide, so $[\text{OH}^-] \approx c(\text{NaOH}) = 0.010 \text{ mol dm}^{-3}$. Therefore:

$$\begin{aligned} [\text{Ni}^{2+}] \times (0.010)^2 &= 5.48 \times 10^{-16} \\ [\text{Ni}^{2+}] &= 5.48 \times 10^{-12} \text{ mol dm}^{-3} \end{aligned}$$

A10.2 *Adsorption*: heavy metal ions are selectively adsorbed (held tightly) on the surface of a suitable solid or gel-like material, such as zeolite or ion-exchange resin. In the case of chemical adsorption, the metal ions form covalent and/or ionic bonds with the adsorbent surface. Physical adsorption involves non-chemical (van der Waals) interactions.

Chelation: heavy metal ions form multiple coordinate bonds with suitable chelating agents (ligands that can donate two or more lone electron pairs to the metal ion). The resulting coordinate compounds (chelate complexes) are very stable, form readily and dissociate to a very small extent, so the equilibrium concentration of free metal ions in the solution becomes very low.

Precipitation: heavy metal ions react with suitable counterions to produce insoluble compounds (salts or hydroxides). These compounds form a solid phase (precipitate or suspension), which can be removed by filtration or by allowing the mixture to settle.

Option B Biochemistry

B1.1 Catabolic, as a larger molecule (peptide) is broken down into smaller units (amino acids and/or shorter-chain peptides).

B1.2 Nearly all condensation reactions in living organisms proceed in aqueous environment and produce water as a by-product, which can be represented by the following general scheme:

$$A-OH(aq) + H-B(aq) \rightleftharpoons AB(aq) + H_2O(l)$$

Since water is also the solvent, it is present in the reaction mixture in a very large excess. At the same time, the reactant concentrations in biological fluids are very low. According to Le Châtelier's principle, these factors make the forward reaction less favourable and thus increase its ΔG value (make it positive).

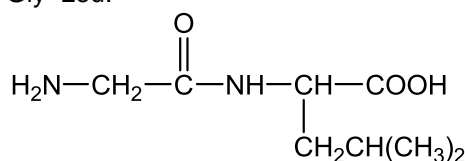
Note that we are talking about the Gibbs free energy (ΔG) of the reaction under *non-standard* conditions. The *standard* Gibbs free energy (ΔG°) of the same reaction could still be negative.

B2.1 a) Glycine: aminoethanoic acid; leucine: 2-amino-4-methylpentanoic acid.

b) Paper chromatography, as both amino acids have identical pI values (6.0) and thus cannot be separated by gel-electrophoresis. Other types of chromatography, such as thin-layer or column, can also be used.

c) Four: Gly–Gly, Gly–Leu, Leu–Gly and Leu–Leu.

d) Gly–Leu:



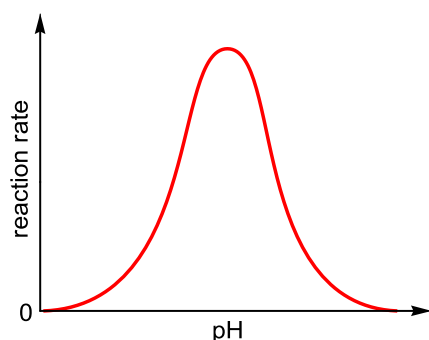
e) *Advantages*: common names are often shorter and easier to memorise than systematic names. The three-letter abbreviations derived from common names, such as Gly for glycine and Leu for leucine, are very convenient and thus widely used in biochemistry and biology. Many common names reflect the properties or natural sources of amino acids (for example, glycine has a sweet taste, so its name was derived from Greek *glukus* "sweet").

Disadvantages: common names must be memorised while systematic names can be constructed using simple and unambiguous rules, which helps communicate scientific knowledge. Systematic names look similar in different languages, which facilitates international collaboration.

B2.2 a) Hydrogen bonds.

b) Amido groups, $\text{C}(\text{O})-\text{NH}$. More specifically, hydrogen bonds form between $\text{C}=\text{O}$ and $\text{N}-\text{H}$ fragments of different amido groups.

B2.3

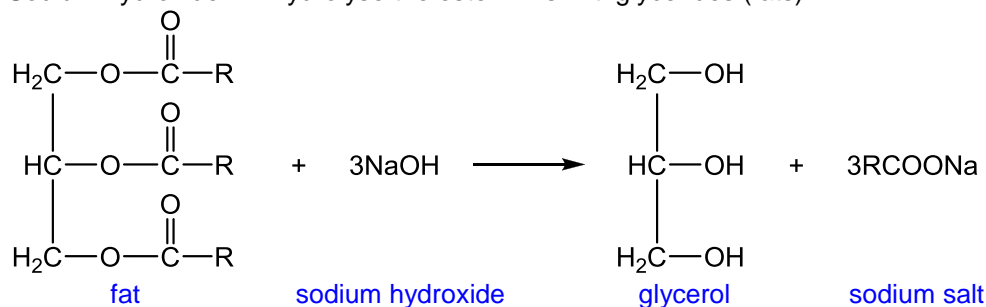


Note that the enzyme activity reaches its maximum at a certain pH (specific to each enzyme) and falls quickly at either side of this optimum pH value. The reaction rate is proportional to the enzyme activity.

B3.1

a) *Physical properties:* at room temperature, oils are liquid while fats are solid.
Chemical composition: oils contain many carbon–carbon double bonds (C=C) while fats contain few or no such bonds. Note that "carbon–carbon" or "C=C" are essential for mark, as both oils and fats are triglycerides and thus contain many carbon–oxygen (C=O) double bonds.

b) Sodium hydroxide will hydrolyse the ester links in triglycerides (fats):



Both products of the reaction, glycerol and sodium salts of fatty acids, are soluble in water, so they will be flushed away from the drains.

- c)** Oil can be hydrogenated by reacting with hydrogen gas at a high temperature and in the presence of a transition metal catalyst (typically Ni or Pt). The hydrogenation converts each carbon–carbon double bond in the oil into a single bond, producing a saturated triglyceride (fat).
- d)** If the hydrogenation is incomplete, some carbon–carbon double bonds will change their configuration from *cis*- to *trans*-, producing *trans*-fats. The consumption of *trans*-fats increases the risk of heart disease, diabetes and obesity.

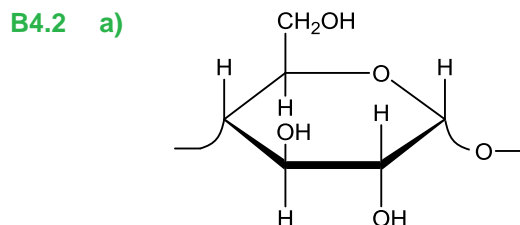
B3.2

a) Hydroxyl (–OH) and carbonyl (C=O).

Note that "alcohol" and "ketone" are class names, not functional group names.

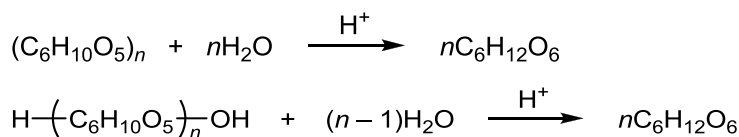
- b)** The steroidal backbone (a characteristic arrangement of four fused rings, three of which are six-membered and one is five-membered).
- c)** More soluble, as DHEA contains a carbonyl group instead of the long hydrocarbon chain in cholesterol. As a result, DHEA is more polar than cholesterol and can form more hydrogen bonds with water.
- d)** A possible answer can include any **one** of the following:
- many anabolic steroids have medical uses (such as accelerated recovery of patients with significant loss of muscle tissue due to surgery, trauma, cancer or other conditions);
 - negative and positive effects of anabolic steroids on human health need to be better understood;
 - the research allows to improve the detection of banned substances.

- B4.1 a)** They both contain a carbonyl (C=O) group and more than one hydroxyl (–OH) groups. Note that "more than one" is essential for mark.
- b)** Threose is an aldose (belongs to the class of aldehydes), as its carbonyl group is located at a terminal (first) carbon atom. Erythrulose is a ketose (belongs to the class of ketones), as its carbonyl group is located at a non-terminal (second) carbon atom.
- c)** Carbohydrates are more soluble in water, as they have many polar functional groups (–OH and C=O) that can form multiple hydrogen bonds with water.



Note that the continuation bonds and their positions (below the plane of the six-membered ring) are essential for mark.

- b)** There are two possible equations:

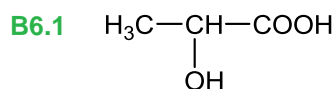


The first equation does not show the terminal groups in the macromolecule of amylose, so each repeating unit requires one molecule of water. The second equation shows these groups, so the number of water molecules is reduced by one. Both equations are equally acceptable, as long as they are balanced.

- B5.1** *Structural:* vitamins A and D have long hydrocarbon chains and a single hydroxyl group (–OH). In contrast, vitamin C has much fewer hydrocarbon fragments but several hydroxyl and other polar functional groups (–O– and C=O).

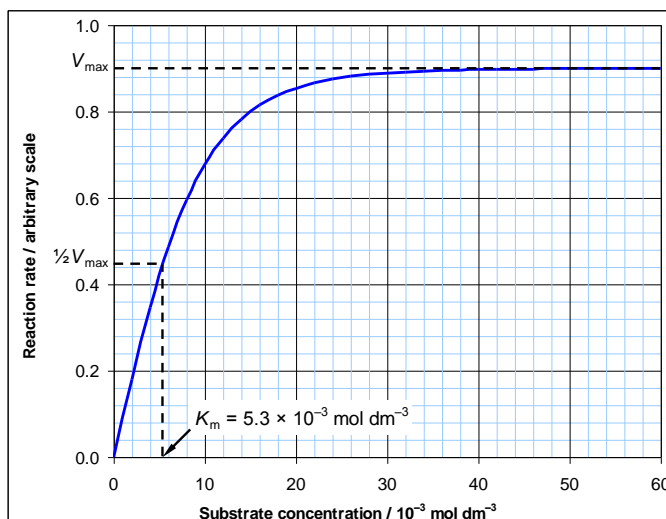
Physical: vitamins A and D have low melting points and are almost insoluble in water but are soluble in non-polar solvents, such as hexane. In contrast, vitamin C has a high melting point and is readily soluble in water but is insoluble in non-polar solvents.

- B5.2 a)** Cholesterol.
- b)** The biosynthesis of vitamin D in the human body (mostly in the skin) requires sunlight. In northern countries, the days are short during the winter, so people have little exposure to sunlight. As a result, the biosynthesis does not produce enough vitamin D, which can lead to a deficiency.



- B6.2** The individual can be given EDTA or any other ligand that forms chelate complexes with lead ions. Chelate complexes are very stable, so the concentration of free lead ions in the blood plasma and other parts of the body will decrease significantly, and the effects of lead poisoning will be reduced.

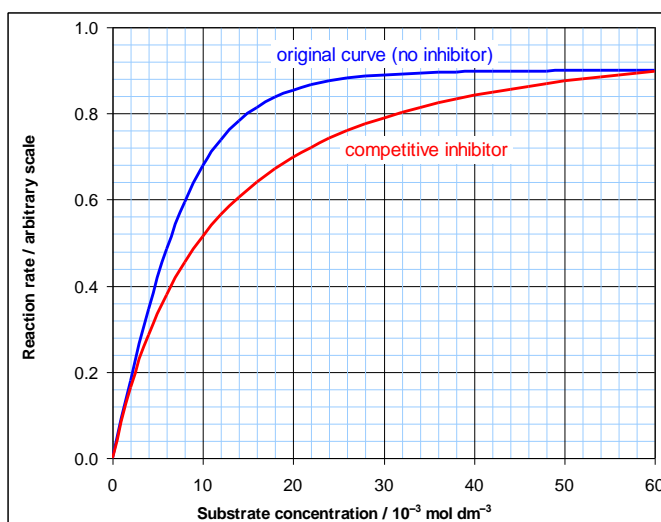
B7.1 a)



Note that K_m is equal to the substrate concentration at $\frac{1}{2} V_{\text{max}}$.

- b) The structures of sulfanilamide and PABA are very similar, so sulfanilamide is likely to act as a competitive inhibitor. The molecule of sulfanilamide occupies the active site of the enzyme and prevents the "normal" substrate (PABA) from binding to the same enzyme.

c)



Note that in the presence of a competitive inhibitor (sulfanilamide) the curve shifts to the right (K_m increases) but flattens out at the same level (V_{max} is not affected).

- B7.2 a) According to section 1 of the data booklet, the pH of a buffer solution can be found using the Henderson–Hasselbalch equation:

$$\text{pH} = \text{p}K_a + \log \frac{[\text{A}^-]}{[\text{HA}]}$$

In our buffer system, the anionic form is the conjugate base (A^-) and the zwitterion is the conjugate acid (HA). Therefore:

$$\text{pH} = 9.13 + \log \frac{0.100}{0.250} \approx 8.73$$

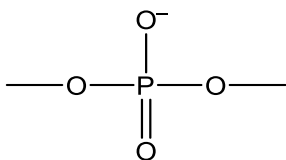
- b)** A series of standard solutions with known concentrations of phenylalanine are prepared, and their absorbances are measured using a UV-vis spectrometer. A calibration curve is constructed as a plot of absorbance against concentration. The absorbance of the studied solution is also measured under exactly the same conditions as the absorbances of standard solutions. The unknown concentration of phenylalanine is then found from the calibration curve.

A less precise method uses the Beer–Lambert law, $A = \epsilon/c$, which is given in section 1 of the data booklet. The absorbance (A_1) of a single standard solution with a known concentration (c_1) of phenylalanine is measured. The absorbance (A_2) of the studied solution is also measured under the same conditions. Since concentration is

proportional to absorbance, $\frac{c_1}{c_2} = \frac{A_1}{A_2}$, so the unknown concentration (c_2) of phenylalanine can be found as follows:

$$c_2 = \frac{A_1}{A_2} c_1$$

- B8.1 a)** Each residue of phosphoric acid in DNA has a free hydroxyl group, which is almost completely ionised under biological conditions ($\text{pH} \approx 7.4$):



The remaining units of the DNA molecule (the residues of deoxyribose and nitrogenous bases) are uncharged, so the whole molecule has a net negative charge.

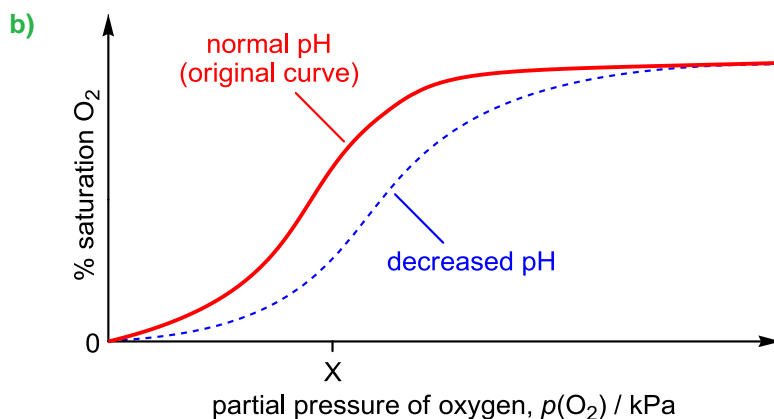
- b)** In the complementary sequence, each "A" will be replaced with "T", "T" with "A", "G" with "C" and "C" with "G": –AGTTACCTG–.

- B8.2 a)**

Polynucleotide	Composition		Structure
	sugar	nitrogenous bases	
DNA	deoxyribose	all except uracil	double strand
RNA	ribose	all except thymine	single strand

- b)** Let $n(\text{adenine}) = 2x$ mol, then $n(\text{guanine}) = 3x$ mol. Since adenine is complementary to thymine, $n(\text{thymine}) = n(\text{adenine}) = 2x$ mol. Similarly, guanine is complementary to cytosine, so $n(\text{cytosine}) = n(\text{guanine}) = 3x$ mol. In such case, the total amount of nitrogenous bases in the DNA sample is $2x + 3x + 2x + 3x = 10x$ mol. Therefore, the mole percentage of cytosine is $\frac{3x}{10x} \times 100\% = 30\%$.

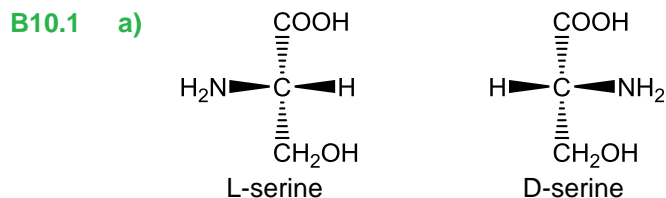
- B9.1 a)** Each hemoglobin molecule has four binding sites for oxygen molecules. At 0 kPa, hemoglobin is completely deoxygenated, and its affinity for oxygen is low, so the curve rises very gradually. When the first oxygen molecule binds to a deoxygenated hemoglobin, the shapes of the other three binding sites change slightly, and their affinities for oxygen increase. This effect is known as cooperative binding. As the second and subsequent oxygen molecules bind to hemoglobin more easily, further increase in $p(\text{O}_2)$ leads to progressively larger increase in hemoglobin saturation. As a result, the saturation curve becomes steeper.



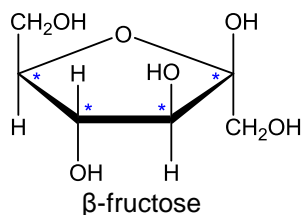
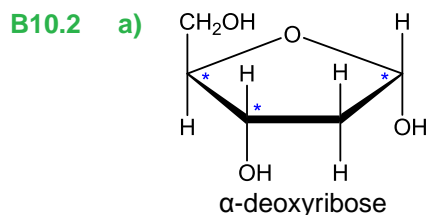
Note that the curve at a decreased pH begins at the origin (% saturation $O_2 = 0$) and flattens out at the same level (% saturation $O_2 = 100$) as the original curve. However, a decrease in pH distorts the shapes of binding sites and thus reduces the affinity of hemoglobin for oxygen. As a result, any given percentage of saturation requires a higher $p(O_2)$, so the curve shifts right.

- c) Hemoglobin has a higher affinity for carbon monoxide (CO) than for oxygen, so the complex of hemoglobin with CO forms very easily and breaks down very slowly. In addition, the presence of a CO molecule in one of the four binding sites of hemoglobin prevents the release of oxygen from other binding sites. As a result, hemoglobin loses the ability to transport oxygen from the lungs to tissues, which causes hypoxia. In severe cases, this condition can be fatal.

- B9.2** a) In all anthocyanins, the flavylium cation (HB^+) has one more proton than the quinoidal base (B). The equilibrium between these two forms can be represented as follows:
 $HB^+(aq) \rightleftharpoons H^+(aq) + B(aq)$
 At low pH, $[H^+]$ is high, so the equilibrium shifts to the left, and the anthocyanins exist predominantly as flavylium cations.
- b) In all anthocyanins, the flavylium cation (HB^+) has one more proton than the quinoidal base (B). The equilibrium between these two forms can be represented as follows:
 $HB^+(aq) \rightleftharpoons H^+(aq) + B(aq)$
 At low pH, $[H^+]$ is high, so the equilibrium shifts to the left, and the anthocyanins exist predominantly as flavylium cations.
- c) Quinoidal base and flavylium cation have different arrangements of delocalised electrons, which affects the extent of electron conjugation in these species and thus the wavelength of light they absorb.
- d) According to the colour wheel in section 17 of the data booklet, the range 600–640 nm corresponds to orange light. If orange light is absorbed, the complementary colour (blue) is observed, so the quinoidal base appears blue.



- b) L-serine.



Note that the right hand side hydroxyl group in the first structure is below the plane of the ring (α -form) while in the second structure it is above the plane of the ring (β -form).

- b)** See part (a). Note that the second carbon atom in deoxyribose is not chiral, as it has two identical substituents (H).

- B10.3 a)** Extensive electron conjugation. Other acceptable answers are "large number of delocalised electrons" and "many alternating single and double bonds". Note that the words "extensive", "large" and "many" are essential for the mark, as molecules with only a few delocalised electrons do not absorb visible light.
- b)** One of the carbon–carbon double bonds in the retinal residue changes its configuration from *cis*- to *trans*-.
- c)** The system of electron conjugation in rhodopsin is larger than that in retinal, so rhodopsin absorbs visible light over a wider range of wavelengths. Retinal strongly absorbs light in the violet region, so it appears yellow (as yellow colour is complementary to violet; see section 17 of the data booklet). Rhodopsin strongly absorbs light in the green and yellow regions, so it transmits red and violet light and thus appears purple.

Option C Energy

C1.1 a) $\Delta H_c^\ominus = 12.0 \text{ MJ mol}^{-1} = 1.20 \times 10^4 \text{ kJ mol}^{-1}$

$$\text{specific energy} = \frac{1.20 \times 10^4 \text{ kJ mol}^{-1}}{299 \text{ g mol}^{-1}} \approx 40.1 \text{ kJ g}^{-1}$$

$$\text{energy density} = 40.1 \text{ kJ g}^{-1} \times 0.850 \text{ g cm}^{-3} \approx 34.1 \text{ kJ cm}^{-3}$$

- b)** *Advantages (any two will score the mark):*

- when burned, ethanol produces less soot and other particulates than biodiesel;
- ethanol has a higher octane rating than biodiesel;
- ethanol has a lower viscosity than biodiesel;
- ethanol can be produced from carbohydrates (instead of triglycerides required for biodiesel);
- in contrast to biodiesel, the production of bioethanol does not require corrosive chemicals (such as strong bases) and high temperature;
- ethanol spills present no long-term environmental hazards (as ethanol is water-soluble and fully biodegradable while biodiesel is not).

Disadvantages (any two will score the mark):

- ethanol has a lower specific energy than biodiesel (so more fuel is needed for travelling the same distance);
- the engine may have to be modified for using ethanol-rich fuels;
- distillation of ethanol requires energy (which further reduces its overall efficiency as a fuel);
- ethanol is hygroscopic (absorbs water), so ethanol-rich fuels can deteriorate over time.
- ethanol is intoxicating (so can be abused).

C1.2 a)

One tonne (1.00×10^6 g) of coal contains $\frac{1.00 \times 10^6 \text{ g}}{100\%} \times 93\% = 9.30 \times 10^5$ g, or

$\frac{9.30 \times 10^5 \text{ g}}{12.01 \text{ g mol}^{-1}} \approx 7.74 \times 10^4$ mol of graphite. According to section 13 of the data booklet, $\Delta H_c^\circ(\text{C, graphite}) = -394 \text{ kJ mol}^{-1}$, so one tonne of coal will produce $7.74 \times 10^4 \text{ mol} \times 394 \text{ kJ mol}^{-1} \approx 3.05 \times 10^7 \text{ kJ} = 30.5 \text{ GJ}$ of energy.

Therefore, the efficiency of energy transfer is $\frac{11.0 \text{ GJ}}{30.5 \text{ GJ}} \times 100\% \approx 36.1\%$.

b) Any **two** of the following will score the full mark:

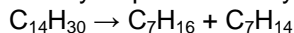
- reduce heat losses to the environment by insulating the combustion chamber;
- use coal with a higher percentage of graphite (so less energy would be wasted on heating up non-combustible material);
- pre-heat the coal and the air used for its combustion with hot flue gases;
- optimise the air to coal ratio (insufficient air would lead to incomplete combustion while excess air would require extra energy for heating);
- convert the coal first into syngas and then burn the syngas instead of coal (as the combustion of a homogeneous gas mixture is easier to optimise and control than the combustion of a heterogeneous mixture of coal and air);
- use hot flue gases instead of electricity for heating the plant itself and the surrounding buildings.

C2.1 a)

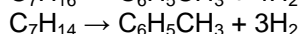
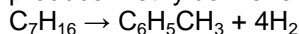
The octane number generally decreases when the number of CH_2 groups in the alkane molecule increases. Therefore, alkanes with long straight chains, such as *n*-octane, have very low octane numbers while short-chain alkanes (such as methane or ethane) and branched alkanes (such as 2,2,4-trimethylpentane, also known under the common name "isooctane") have high octane numbers.

Note that cycloalkanes and aromatic hydrocarbons also have higher octane numbers than straight-chain alkanes. However, the question specifically asks about alkanes, so such answers will not be accepted.

b) The first step is the cracking of tetradecane, which proceeds at high temperatures and usually requires a catalyst:



Both heptane (C_7H_{16}) and heptene (C_7H_{14}) undergo catalytic reforming reactions and produce methylbenzene ($\text{C}_6\text{H}_5\text{CH}_3$):

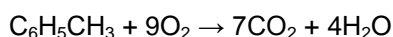


Catalytic reforming also requires high temperature and a catalyst.

c) $m(\text{C}_6\text{H}_5\text{CH}_3) = 2.00 \times 10^3 \text{ kg} = 2.00 \times 10^6 \text{ g}$

$$M(\text{C}_6\text{H}_5\text{CH}_3) = 92.15 \text{ g mol}^{-1}$$

$$n(\text{C}_6\text{H}_5\text{CH}_3) = \frac{2.00 \times 10^6 \text{ g}}{92.15 \text{ g mol}^{-1}} \approx 2.17 \times 10^4 \text{ mol}$$

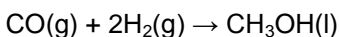


$$n(\text{CO}_2) = 7 \times n(\text{C}_6\text{H}_5\text{CH}_3) = 7 \times 2.17 \times 10^4 \text{ mol} \approx 1.52 \times 10^5 \text{ mol}$$

$$M(\text{CO}_2) = 44.01 \text{ g mol}^{-1}$$

$$m(\text{CO}_2) = 1.52 \times 10^5 \text{ mol} \times 44.01 \text{ g mol}^{-1} \approx 6.69 \times 10^6 \text{ g} = 6.69 \text{ tonnes.}$$

C2.2 a)



- b) There are several possible equations, for example:
 $7\text{CH}_3\text{OH}(\text{l}) + \text{H}_2(\text{g}) \rightarrow \text{C}_7\text{H}_{16}(\text{l}) + 7\text{H}_2\text{O}(\text{l})$
 $15\text{CH}_3\text{OH}(\text{l}) \rightarrow 2\text{C}_7\text{H}_{16}(\text{l}) + 14\text{H}_2\text{O}(\text{l}) + \text{CO}(\text{g})$

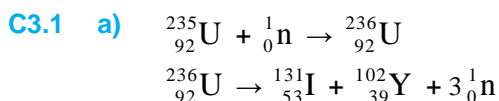
Note that the catalytic dehydration of methanol initially produces alkenes, which are then reduced to alkanes. Therefore, the conversion of methanol to alkanes requires extra hydrogen, which can be either added to the reaction mixture directly (as it is done in the first equation) or produced inside the reaction chamber by the decomposition of methanol:



The latter equation is the reverse of the equation from part (a).

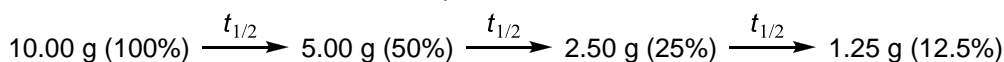
- c) Your answer should include at least one advantage and one disadvantage for each fuel, which are outlined in the table below.

Fuel	Advantages	Disadvantages
methanol	high octane rating, produces less soot and particulates when burned, water-soluble and biodegradable (so spills cause no long-term environmental hazards)	low specific energy and energy density, absorbs water (so fuel may deteriorate over time), toxic, engines must be modified to run on methanol-rich fuels
<i>n</i> -heptane	high specific energy and energy density, can be used in most internal combustion engines	low octane rating, produces soot and particulates, insoluble in water and non-biodegradable



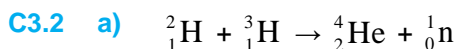
The atomic numbers (bottom-left subscript indexes) can be omitted.

- b) The mass of uranium-235 in the sample will decrease as follows:



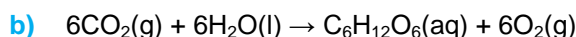
The decay from 10 to 1.25 g will take three half-lives, or $3 \times 7.038 \times 10^6 \approx 2.11 \times 10^7$ years.

- c) High-level nuclear waste (HLW).



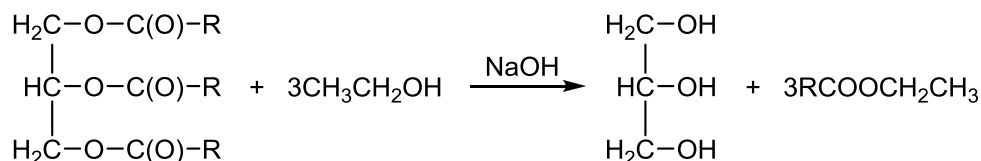
- b) According to section 36 of the data booklet, helium has a higher binding energy per nucleon than deuterium and tritium. If binding energy increases, the products of the reaction (helium-4 and a neutron) are more stable than the reactants (deuterium and tritium). Therefore, excess energy is released.
- c) Spectrometry. Note that the answer "spectroscopy" may fail to score the mark, as the question refers to relative abundances ("mainly composed"), and the determination of element abundances requires quantitative measurements.

- C4.1 a) Chlorophyll has many alternating single and double bonds. The π -electrons in these bonds are delocalised and form a large system of electron conjugation. The energy of electron transitions in this conjugated system is similar to that of photons of visible light.



- c) Ethanol can be produced by fermentation of glucose:
 $\text{C}_6\text{H}_{12}\text{O}_6(\text{aq}) \rightarrow 2\text{CH}_3\text{CH}_2\text{OH}(\text{aq}) + 2\text{CO}_2(\text{g})$

- C4.2 a)** The oil can be treated with excess ethanol at a high temperature in the presence of a catalyst (a strong base or a strong acid):



The ethyl esters of fatty acids, $\text{RCOOCH}_2\text{CH}_3$, have lower viscosity than the original oil.

- b)** Biofuels are produced from plant material. When plants grow, they remove carbon dioxide from the atmosphere. When the biofuel is combusted, the carbon dioxide returns to the atmosphere, so the net carbon emission of the whole process is close to zero. In contrast, the release of carbon dioxide from fossil fuels is not compensated by its removal from the atmosphere.

- C5.1 a)** Your answer may include any the following:

- sufficient data on global temperature and carbon dioxide levels have been collected;
- better understanding of natural processes has been achieved;
- comprehensive computer models of the Earth's climate have been developed;
- more powerful computers can now process data more efficiently.

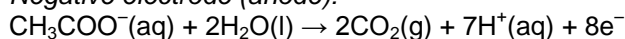
- b)** Modes II (asymmetric stretching) and III (bending) will be IR-active, as they change the dipole moment of the CO_2 molecule. Mode I (symmetric stretching) will be IR-inactive, as it does not affect the dipole moment of the CO_2 molecule (the dipole moment will remain zero).

- c)** A significant proportion of atmospheric carbon dioxide dissolves in oceanic water:
 $\text{CO}_2(\text{g}) \rightleftharpoons \text{CO}_2(\text{aq}) \quad \Delta H^\circ < 0$

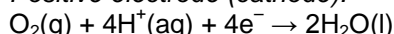
This process is exothermic, so when the temperature of oceanic water rises, the solubility of carbon dioxide decreases. The position of the above equilibrium shifts to the left, and the concentration of carbon dioxide in the atmosphere increases.

- d)** Particulates cause global dimming by absorbing sunlight and reflecting it back into the space. As a result, less sunlight reaches the Earth's surface, so the temperature of the Earth's surface decreases.

- C6.1 a)** *Negative electrode (anode):*



Positive electrode (cathode):



Overall reaction:



- b) Your answer should include at least one similarity and one difference, which are outlined in the table below.

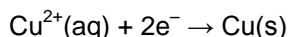
	Primary cells	Microbial fuel cells (MFCs)
similarities	transform chemical energy into electrical energy; contain electrodes and electrolyte; use spontaneous redox reactions; cannot be recharged / the redox reactions cannot be reversed using external electric current	
differences	contain the reactants within the cell; can be used only once and for a limited period of time; long (although not indefinite) shelf life; can operate in a wider range of temperatures; usually contain heavy metals and must be disposed of as hazardous waste	require constant supply of fuel; can be used continuously (as long as the fuel is supplied); cannot be stored for a long time without fuel supply (as bacteria will die); can operate only in narrow ranges of temperature and pH; biodegradable (except the electrodes)

- c) **Voltage:** material(s) of the electrodes; redox reactions / qualitative composition of the electrolyte(s); temperature; pH / concentration of ions in the electrolyte(s).

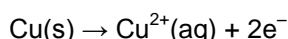
Current: diffusion rate of ions; internal resistance; temperature, pH / concentration of ions in the electrolyte(s); size/surface area/separation of the electrodes; composition and construction of the salt bridge.

Note that you need to state at least two different factors. For example, the answer "temperature" will be accepted for either voltage or current but not for both.

- C6.2 a) The driving force of all redox processes in a concentration cell is the difference in concentrations of the same ion (in our case, Cu^{2+}) between the two half-cells. The ions with the higher concentration will produce a higher redox potential and thus undergo reduction:



Therefore, the half-cell with $[\text{Cu}^{2+}] = 750 \text{ mmol dm}^{-3}$ will be the cathode (positive electrode). The other half-cell with $[\text{Cu}^{2+}] = 250 \text{ mmol dm}^{-3}$ will be the anode (negative electrode), where copper(II) ions will be produced:



The same conclusion can be made using the Nernst equation.

- b) For a concentration cell, $E^{\circ}_{\text{cell}} = 0$, as both half-cells contain identical redox pairs. According to section 1 of the data booklet,

$$E_{\text{cell}} = E^{\circ}_{\text{cell}} + \frac{RT}{nF} \ln Q = 0 - \frac{8.31 \times 298}{2 \times 96500} \ln \frac{0.150}{0.750} \approx 0.021 \text{ V} = 21 \text{ mV}$$

- c) Your answer may include any **two** of the differences outlined in the table below.

Difference	Concentration cell	Standard voltaic cell
redox pairs in half-cells	identical	different
materials of the electrodes	identical	different or identical
qualitative composition of electrolytes	identical	different or identical
concentrations of electrolytes	different	identical (1 mol dm^{-3})
E°_{cell}	0	$\neq 0$

- C7.1 a)** According to sections 2 and 4 of the data booklet, $1 \text{ amu} = 1.66 \times 10^{-27} \text{ kg}$ and $m({}_0^1\text{n}) = 1.674927 \times 10^{-27} \text{ kg}$. Therefore:

$$m({}_0^1\text{n}) = \frac{1.674927 \times 10^{-27}}{1.66 \times 10^{-27}} \approx 1.00899 \text{ amu}$$

$$\Delta m = (2.01410 + 3.01605 - 4.00260 - 1.00899) \times 1.66 \times 10^{-27} \approx 3.08 \times 10^{-29} \text{ kg}$$

If you rounded the mass of the neutron in amu to three significant figures, your answer would be $2.91 \times 10^{-29} \text{ kg}$, which is also acceptable.

b)
$$n(\text{helium-4}) = \frac{1.00 \text{ g}}{4.00260 \text{ g mol}^{-1}} \approx 0.250 \text{ mol}$$

$$N(\text{helium-4}) = 0.250 \text{ mol} \times 6.02 \times 10^{23} \text{ mol}^{-1} = 1.505 \times 10^{23} \text{ (atoms)}$$

$$\Delta m(\text{per } 0.25 \text{ mol of helium-4}) = 3.08 \times 10^{-29} \text{ kg} \times 1.505 \times 10^{23} \approx 4.64 \times 10^{-6} \text{ kg}$$

$$E = mc^2 = 4.64 \times 10^{-6} \text{ kg} \times (3.00 \times 10^8 \text{ m s}^{-1})^2 \approx 4.18 \times 10^{11} \text{ J}$$

The acceptable range of answers is from 3.90×10^{-6} to $4.30 \times 10^{-6} \text{ kg}$

- c)** A tritium nucleus contains one proton ($m = 1.672622 \times 10^{-27} \text{ kg}$; see section 4 of the data booklet) and two neutrons ($m = 1.674927 \times 10^{-27} \text{ kg}$ each). Therefore:

$$m(\text{tritium atom}) = 3.01605 \times 1.66 \times 10^{-27} \text{ kg} \approx 5.006643 \times 10^{-27} \text{ kg}$$

$$\Delta m = 1.672622 \times 10^{-27} + 2 \times 1.674927 \times 10^{-27} - 5.006643 \times 10^{-27} \approx 1.58 \times 10^{-29} \text{ kg}$$

$$E(\text{per atom}) = mc^2 = 1.58 \times 10^{-29} \text{ kg} \times (3.00 \times 10^8 \text{ m s}^{-1})^2 \approx 1.42 \times 10^{-12} \text{ J}$$

$$E(\text{per nucleon}) = \frac{E(\text{per atom})}{3} = \frac{1.42 \times 10^{-12} \text{ J}}{3} \approx 4.73 \times 10^{-13} \text{ J}$$

The acceptable range of answers is from 3.70×10^{-6} to $4.90 \times 10^{-6} \text{ kg}$

- d)** According to section 1 of the data booklet, $t_{1/2} = \frac{\ln 2}{\lambda}$ and $N = N_0 e^{-\lambda t}$. Therefore:

$$t_{1/2} = \frac{0.693}{0.0563 \text{ year}^{-1}} \approx 12.3 \text{ years}$$

$$N(\text{remaining}) = N_0 \times e^{-0.0563 \times 45} \approx 0.0794 \times N_0 = 7.94\%$$

$$N(\text{decayed}) = 100\% - 7.94\% \approx 92.1\%$$

- C8.1** Retinal is yellow, so it absorbs the complementary violet light (400–424 nm, see section 17 of the data booklet). Carotene is orange, so it absorbs the complementary blue light (424–491 nm).

Note that the system of electron conjugation in carotene is larger than that in retinal, so carotene absorbs visible light of longer wavelengths.

- C8.2 a)** In DSSCs, the absorption of photons occurs in a metal-based organic dye while the charge separation involves the dye, a semiconductor (titanium dioxide) and an electrolyte (I^-/I_3^-). In silicon-based photovoltaic cells both processes take place simultaneously within a semiconductor (doped silicon).
- b)** Your answer should include any **two** advantages listed in table C.8.1.

Option D Medicinal chemistry

- D1.1 a)** Your answer should include any **two** of the following: hydroxyl, carboxyl, ether and amido. The answer "amino" is incorrect, as all NH and NH_2 fragments in zanamivir are parts of larger functional groups. Note that "alcohol", "carboxylic acid", "amide" and "amine" are class names, not functional group names.
- b)** Zanamivir is a highly polar molecule, as it contains many polar functional groups. Polar molecules are poorly absorbed through the skin (transdermally), so zanamivir must be administered by inhalation.

- D1.2 a)** It is not possible to determine ED_{100} for all drugs, as the efficacy of a drug varies among individuals. Some individuals can be completely unresponsive to certain drugs, so ED_{100} will never be achieved.
- b)** Ethics and cost. It is unethical to put animals or people in danger unless absolutely necessary. Animal and human trials of drugs are expensive.

- D1.3 a)** Enzymes and cellular receptors. The more general answer "proteins" is also acceptable. Nucleic acids can also be targeted by drugs, but this is less common.
- b)** A drug molecule can bind (temporary or permanently) to the active or allosteric site of an enzyme or receptor. The binding can be covalent or non-covalent (hydrogen bonding, ionic, dipole–dipole and/or London dispersion forces).

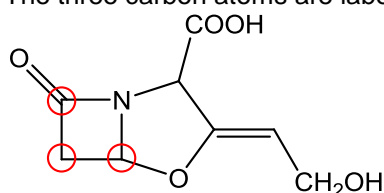
- D2.1 a)** $n(\text{salicylic acid}) = 2.65 \text{ g} / 138.13 \text{ g mol}^{-1} \approx 0.0192 \text{ mol}$
 $n(\text{ethanoic anhydride}) = 2.51 \text{ g} / 102.10 \text{ g mol}^{-1} \approx 0.0246 \text{ mol}$
 Since $n(\text{salicylic acid}) < n(\text{ethanoic anhydride})$, salicylic acid is the limiting reactant.

- b)** $M(\text{aspirin}) = 180.17 \text{ g mol}^{-1}$ (see example D.2.1)
 $m_{\text{theor}}(\text{aspirin}) = 0.0192 \text{ mol} \times 180.17 \text{ g mol}^{-1} \approx 3.46 \text{ g}$

$$m_{\text{pract}}(\text{aspirin}) = \frac{3.46 \text{ g} \times 72.5\%}{100\%} \approx 2.51 \text{ g}$$

- c)** Your answer should include any **three** of the following: IR spectroscopy, NMR spectroscopy, mass spectroscopy, UV-vis spectroscopy, X-ray crystallography, elemental analysis, chromatography, melting point determination.

- D2.2 a)** Ring strain is the decreased stability of a cyclic molecule due to unusual bond angles.
- b)** The three carbon atoms are labelled with red circles.



Note that the ring strain of carbon atoms in the five-membered ring is negligible.

- c)** The structure of clavulanic acid is similar to that of penicillin, so β -lactamase attacks clavulanic acid instead of penicillin. When clavulanic acid binds to the active site of β -lactamase, the enzyme is inactivated permanently. Inactivated β -lactamase cannot destroy penicillin, so the remaining penicillin molecules can reach their target (transpeptidase).

- D3.1 a)** There are several possible answers, two of which are given in the table below:

Reagent	By-product
ethanoic anhydride, $(\text{CH}_3\text{CO})_2\text{O}$	ethanoic acid, CH_3COOH
ethanoyl chloride, $\text{CH}_3\text{C}(\text{O})\text{Cl}$	hydrogen chloride, HCl

- b) The similarities and differences are outlined in the table below. To score the full mark, you should mention the similarity and at least one difference.

	Mild analgesics	Strong analgesics
similarity	reduce pain	
differences	act at the site of pain/injury; bind to and inhibit the enzymes (cyclooxygenases) that produce pain-sensitising substances (prostaglandins); usually reduce inflammation	bind to opioid receptors in the brain/CNS; block the transmission of pain impulses from the source of pain to the brain; usually do not reduce inflammation

- D3.2 a) Your answer should include any **two** similarities and any **two** differences, which are outlined in the table below.

	Methadone	Diamorphine
similarities	both contain aromatic ring(s), carbonyl group(s) and a tertiary amino group	
differences	two aromatic rings; no carbon-carbon double bonds; no ester/ethanoate groups; no ether groups; no fused rings	only one aromatic ring; one carbon-carbon double bond; two ester/ethanoate groups; one ether group; several fused rings

- b) Methadone reduces the craving for heroin by preventing/managing the withdrawal symptoms. It also reduces the psychological dependence on heroin by breaking the link between the drug use and pleasure (euphoria).

- D4.1 a) $\text{HCl(aq)} + \text{NaHCO}_3\text{(aq)} \rightarrow \text{NaCl(aq)} + \text{CO}_2\text{(g)} + \text{H}_2\text{O(l)}$
or
 $\text{H}^+\text{(aq)} + \text{HCO}_3^-\text{(aq)} \rightarrow \text{CO}_2\text{(g)} + \text{H}_2\text{O(l)}$

Either molecular or ionic equation is *acceptable*. $\text{H}_3\text{O}^+\text{(aq)}$ can be used instead of $\text{H}^+\text{(aq)}$.

- b) $M(\text{NaHCO}_3) = 84.01 \text{ g mol}^{-1}$

$$n(\text{NaHCO}_3) = 0.800 \text{ g} / 84.01 \text{ g mol}^{-1} \approx 0.00952 \text{ mol}$$

According to the equation from part (a), $n(\text{HCl}) = n(\text{NaHCO}_3) = 0.00952 \text{ mol}$

- c) Your answer should include at least one similarity and one difference from the table below.

	Antacids	Omeprazole
similarities	both reduce the pH of the gastric juice; both can cause diarrhea	
differences	relieve heartburn/indigestion; immediate effect; short duration action; disturb electrolyte balance; may cause bloating, belching and the formation of kidney stones	prevent heartburn/indigestion; gradual effect; long duration of action; systemic side-effects; may cause headache, nausea, fatigue and dizziness

Note that the question is about the use of the drugs, not about the mechanism of their action.

D4.2 $M(\text{Na}_2\text{CO}_3) = 105.99 \text{ g mol}^{-1}$
 $n(\text{Na}_2\text{CO}_3) = 0.400 \text{ g} / 105.99 \text{ g mol}^{-1} \approx 0.00377 \text{ mol}$
 $c(\text{Na}_2\text{CO}_3) = 0.00377 \text{ mol} / 0.0500 \text{ dm}^3 = 0.0754 \text{ mol dm}^{-3}$

The dissociation of Na_2CO_3 will produce $\text{CO}_3^{2-}(\text{aq})$ ions, which will act as the conjugate base of the buffer system. The dissociation of NaHCO_3 will produce $\text{HCO}_3^-(\text{aq})$ ions, which will act as the conjugate acid. Therefore:

$$\text{pH} = 10.35 + \log \frac{0.0754 \text{ mol dm}^{-3}}{0.200 \text{ mol dm}^{-3}} \approx 9.93$$

Note that the Henderson–Hasselbalch equation is given in section 1 of the data booklet.

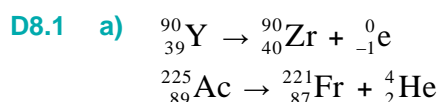
- D5.1** **a)** Ester (general name) or ethoxycarbonyl (specific name). Any of the two answers is acceptable.
- b)** The replacement of a highly polar carboxyl ($-\text{COOH}$) group with a less polar ester ($-\text{COOCH}_2\text{CH}_3$) group makes the whole drug molecule less polar, so it could pass lipid-based cell membranes more easily.

- D5.2** **a)** Your answer should contain any **two** similarities and any **two** differences from the table below.

	Viruses	Bacteria
similarities	both contain genetic material; both can cause infectious diseases	
differences	smaller than bacteria; lack cellular structure; lack metabolism; cannot feed, excrete or grow; can multiply only within host cells	larger than viruses; have cellular structure; have metabolism; can feed, excrete and grow; can multiply on their own

- b)** Viruses mutate quickly and eventually develop resistance to antiviral drugs, including rimantadine.
- c)** Poorly educated people are less capable to protect themselves and their partners from HIV. They are also less likely to recognise the symptoms of AIDS and seek medical help. Finally, they are more likely to deny the existence of HIV/AIDS and refuse to take actions against the spread and prevention of this virus/disease.
The stigma associated with HIV/AIDS prevents some people from taking HIV tests, reporting their symptoms and/or receiving medical treatment.
- D6.1** **a)** Your answer should include any **two** specific examples, such as needles, syringes, bottles/containers, solutions, gloves, gowns/protective clothing, shoe covers, cotton swabs/tissue, tools.
- b)** *Type:* low-level nuclear waste (LLW).
Characteristics: low activity **and** short half-life.
- c)** Your answer should include any **two** of the following:
- risk to benefit ratio (the harm done to the patient might outweigh the benefits);
 - risk to medical/laboratory staff (exposure to nuclear radiation may cause cancer or other health issues);
 - risk to general public (accidents can expose many people to nuclear radiation);
 - environmental concerns (nuclear waste may cause damage to living organisms);
 - security risks (radioactive materials may be stolen and used by criminals);
 - cost and accessibility (nuclear treatment may not be available to some patients);
 - personal beliefs (cultural resistance, superstition and/or lack of education).

- D6.2 a)** Your answer should include at least one common hazard and at least one specific hazard for each solvent type. These hazards are listed in table D.6.2.
- b)** Your answer may include any **one** of the following: use solvent-free reactions, recycle or reuse solvents, use water or supercritical carbon dioxide as solvents, use "green"/biodegradable solvents (such as dimethyl carbonate or ethanol).
- D7.1** Your discussion should include any **two** of the following:
- sustainability (the risk of extinction of Pacific yew and the need of sustainable use of European yew);
 - environmental pollution (solvent and chemical waste generated during the extraction and/or production of taxol and its precursors);
 - risk to benefit ratio (the harm done to the patient might outweigh the benefits of the anti-cancer treatment);
 - high cost of taxol (so it may not be available to some patients).
- D7.2** A chiral auxiliary binds to a non-chiral precursor, producing a chiral intermediate. When this intermediate reacts with a non-chiral reagent, the existing chiral centre creates steric hindrance and favours the formation of specific enantiomer. After the reaction is complete, the chiral auxiliary is removed, releasing esomeprazole.
- D7.3** The mixture is not racemic (or the rotation angle would be zero).



The atomic numbers (bottom-left subscript indexes) can be omitted.

- b)** Your answer should contain at least **one** similarity and at least **one** difference from the table below.

	Yttrium-90	Actinium-225
similarities	both are used in internal radiotherapy; both can be delivered to cancer cells by carrier drugs/proteins/antibodies; both can be used to selectively destroy cancer cells with little damage to surrounding tissues	
differences	emits mostly β -radiation; β -radiation has lower ionising power but higher penetrating power than α -radiation; used for the treatment of smaller tumours; produces some γ -radiation, which can be used for radioimaging	emits α -radiation; α -radiation has higher ionising power but lower penetrating power than β -radiation; used for the treatment of larger tumours; does not produce γ -radiation, so cannot be used for radioimaging

- c)** See the answer to part (c) of practice problem 1 from topic D.6.
- D8.2 a)**
- $${}_{53}^{131}\text{I} \rightarrow {}_{54}^{131}\text{Xe}^* + {}_{-1}^0\text{e}^-$$
- $${}_{54}^{131}\text{Xe}^* \rightarrow {}_{54}^{131}\text{Xe} + {}_0^0\gamma$$
- The atomic numbers (bottom-left subscript indexes) can be omitted.

- b) Beta-radiation (${}_{-1}^0\text{e}^-$) has higher ionising power but lower penetrating power than gamma-radiation (${}_{0}^0\gamma$), so it causes more damage to cancer cells and less damage to surrounding tissues. In contrast, the penetrating power of gamma-radiation is sufficient for leaving the patient's body and reaching the external imaging equipment. Therefore, beta-radiation is used for cancer treatment while gamma-radiation is used for radioimaging.
- c) According to section 1 of the data booklet, $N_t = N_0 \times (0.5)^{t/t_{1/2}}$. If 99% of the sample decays, 1% will remain. Therefore:
- $$1\% = 100\% \times (0.5)^{t/8.02}$$
- $$\log(0.01) = \frac{t}{8.02} \times \log(0.5)$$
- $$t \approx 53.3 \text{ days.}$$

D9.1 a) Your answer should include any **two** of the following:

- 3200–3600 cm^{-1} due to the O–H bond in the hydroxyl group;
- 2500–3000 cm^{-1} due to the O–H bond in the carboxyl group;
- 1700–1750 cm^{-1} due to the C=O bond in the carboxyl group;
- 1050–1410 cm^{-1} due to the C–O bond in the carboxyl group.

Note that typical IR absorptions are listed in section 26 of the data booklet.

- b) Your answer should contain at least **one** similarity and at least **one** difference from the table below.

	Salicylic acid	Aspirin
similarities	a singlet of the –COOH proton at 9.0–13.0 ppm; the total number of signals is two (besides the signals of the benzene ring)	
differences	a singlet of the –OH proton at 4.0–12.0 ppm; the integration ratio of the two signals is 1 : 1; both singlets/signals are broad	a singlet of the –OC(O)CH ₃ protons at 2.0–2.5 ppm; the integration ratio of the two signals is 1 : 3; one singlet/signal is broad while another one is sharp

Note that the chemical shifts of typical ${}^1\text{H}$ NMR signals are listed in section 27 of the data booklet.

- c) Your answer should contain any **two** of the following: mass spectroscopy, UV-vis spectroscopy, X-ray crystallography, elemental analysis, chromatography, melting point determination.
- D9.2 a) A sample is vaporised and injected into a GC column. The individual compounds in the sample have different retention times and thus separate into individual bands. The MS of each band is checked for specific m/z peaks or compared with computer databases of known anabolic steroids.
- b) Nandrolone, as its rounded M_r value is 274. This value matches the highest m/z value, which is likely to be produced by the molecular ion of nandrolone. Conversely, the rounded M_r value of testosterone is 276, but there is no peak with such m/z value in the mass spectrum.

IB Prepared Chemistry

Answers to practice exam papers

Here are the answers to the practice exam papers from *IB Prepared Chemistry*.

For direct access, click on the paper below.

Paper 1

Paper 2

Paper 3

Paper 1

- | | | |
|-------|-------|-------|
| 1. D | 18. D | 35. A |
| 2. C | 19. B | 36. A |
| 3. C | 20. C | 37. D |
| 4. B | 21. A | 38. B |
| 5. C | 22. B | 39. C |
| 6. A | 23. C | 40. B |
| 7. D | 24. B | 41. B |
| 8. D | 25. D | 42. C |
| 9. B | 26. A | 43. B |
| 10. A | 27. C | 44. C |
| 11. A | 28. D | 45. B |
| 12. C | 29. B | 46. D |
| 13. D | 30. A | 47. B |
| 14. B | 31. B | 48. A |
| 15. C | 32. C | 49. C |
| 16. A | 33. D | 50. D |
| 17. A | 34. A | |

Paper 2

1. (a) To score the full mark, you must state that the acid–base properties of the oxides change from basic through amphoteric to acidic and write at least two chemical equations from the table below.

Oxide	Properties	Equation(s)
MgO	basic	$\text{MgO(s)} + 2\text{HCl(aq)} \rightarrow \text{MgCl}_2\text{(aq)} + \text{H}_2\text{O(l)}$
Al_2O_3	amphoteric	$\text{Al}_2\text{O}_3\text{(s)} + 6\text{HCl(aq)} \rightarrow 2\text{AlCl}_3\text{(aq)} + 3\text{H}_2\text{O(l)}$ $\text{Al}_2\text{O}_3\text{(s)} + 2\text{NaOH(aq)} + 3\text{H}_2\text{O(l)} \rightarrow 2\text{Na[Al(OH)}_4\text{](aq)}$ or $\text{Al}_2\text{O}_3\text{(s)} + 2\text{NaOH(s)} \xrightarrow{\text{heat}} 2\text{NaAlO}_2\text{(s)} + \text{H}_2\text{O(g)}$
SiO_2	acidic	$\text{SiO}_2\text{(s)} + 2\text{NaOH(aq)} \rightarrow \text{Na}_2\text{SiO}_3\text{(aq)} + \text{H}_2\text{O(l)}$
P_4O_{10}		$\text{P}_4\text{O}_{10}\text{(s)} + 12\text{NaOH(aq)} \rightarrow 4\text{Na}_3\text{PO}_4\text{(aq)} + 6\text{H}_2\text{O(l)}$
SO_2		$\text{SO}_2\text{(g)} + 2\text{NaOH(aq)} \rightarrow \text{Na}_2\text{SO}_3\text{(aq)} + \text{H}_2\text{O(l)}$
SO_3		$\text{SO}_3\text{(l)} + 2\text{NaOH(aq)} \rightarrow \text{Na}_2\text{SO}_4\text{(aq)} + \text{H}_2\text{O(l)}$

Ionic equations are also acceptable. State symbols are not required.

- (b) Mg: $1s^2 2s^2 2p^6 3s^2$
 S: $1s^2 2s^2 2p^6 3s^2 3p^4$

- (c) By losing one of its 3s electrons, magnesium gets closer to the stable electron configuration [Ne]. In contrast, when sulfur loses one of its 3p electrons, it gets further from the next stable electron configuration [Ar]. Therefore, the IE_1 of magnesium is lower than that of sulfur.

Magnesium can gain an electron only by accommodating it in the next energy sublevel, 3p, which is unfavourable. In addition, this will bring magnesium further from the stable electron configuration [Ne]. In contrast, sulfur can accommodate an extra electron in its partly filled 3p sublevel and get closer to the next stable electron configuration [Ar]. Therefore, the E_{ea} of sulfur is lower (more negative) than that of magnesium.

Note that explanations based on the positions of magnesium and sulfur in the periodic table, general trends of IE_1 and E_{ea} in periods or the nuclear charges and atomic sizes of these elements will not be accepted, as your answer must refer to electron configurations from part (b).

- (d) In the following calculations, some intermediate results are rounded to four significant figures (one more than needed). The final results are rounded to the correct number of significant figures (three).

- (i) $\text{Mg(s)} + \text{S(s)} \rightarrow \text{MgS(s)}$
 $n(\text{Mg}) = 0.500 \text{ g} / 24.31 \text{ g mol}^{-1} \approx 0.02057 \text{ mol}$
 $n(\text{S}) = 0.500 \text{ g} / 32.07 \text{ g mol}^{-1} \approx 0.01559 \text{ mol}$
 Sulfur is the limiting reactant, so $n_{\text{theor}}(\text{MgS}) = n(\text{S}) = 0.01559 \text{ mol}$
 $n(\text{MgS}) = 0.01559 \text{ mol} \times (24.31 \text{ g mol}^{-1} + 32.07 \text{ g mol}^{-1}) \approx 0.879 \text{ g}$

- (ii) If sulfur is used up completely, there will be $0.02057 - 0.01559 = 0.00498$ mol of unreacted magnesium in the final mixture.

$$m_{\text{final}}(\text{Mg}) = 0.00498 \text{ mol} \times 24.31 \text{ g mol}^{-1} \approx 0.121 \text{ g}$$

$$m_{\text{final}}(\text{mixture}) = 0.879 \text{ g} + 0.121 \text{ g} = 1.000 \text{ g}$$

$$\omega(\text{MgS}) = (0.879 \text{ g} / 1.000 \text{ g}) \times 100\% = 87.9\%$$

$$\omega(\text{Mg}) = 100\% - 87.9\% = 12.1\%$$

- (e) (i) Your answer should include any two of the following:

- the solids dissolve;
- bubbles of gas are produced;
- the mixture/solution becomes warm/hot;
- a smell of rotten eggs appears.

Note that the smell might not appear if the experiment is carried out in a fume cupboard. Answers like “magnesium/magnesium sulfide reacts with the acid”, “hydrogen/hydrogen sulfide is given off”, “energy is released” or “magnesium chloride forms” will not be accepted, as you must refer to observable changes, such as changes in state, temperature, smell and so on.

- (ii) Hydrogen sulfide, $\text{H}_2\text{S}(\text{g})$, is toxic and has a foul smell, so students must not inhale it.

- (f) In the solid state, all Mg^{2+} and S^{2-} ions occupy fixed positions in the crystal lattice and cannot move. In molten magnesium sulfide, these ions move freely and thus can carry electrical charge through the sample.

2. (a) Iodine and bromine are both non-metals with similar electronegativities (2.7 and 3.0, respectively), so the I–Br bond is covalent.

Alternatively, your answer can be based on the bonding triangle:
 $\Delta\chi = 3.0 - 2.7 = 0.3$, $\bar{\chi} = (3.0 + 2.7) / 2 \approx 2.9$, so the bond is covalent.

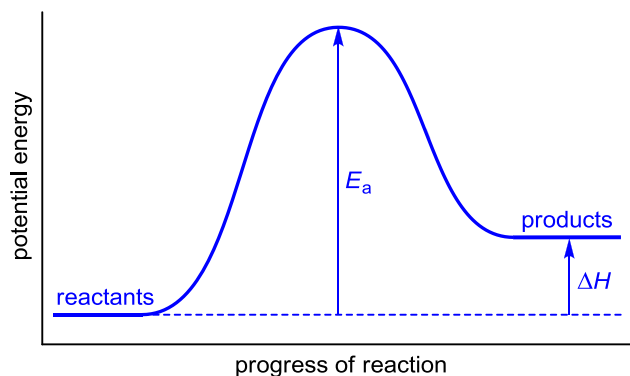
- (b) Simple molecular, as both elements in IBr are covalently bonded to each other and have complete octets of electrons. Another reason is the fact that IBr is volatile under standard conditions and has low melting and boiling points.

- (c) Dipole–dipole forces (as the I–Br bonds are slightly polar due to the difference in electronegativity between iodine and bromine) and London dispersion forces (these forces exist in all substances).

- (d) (i)

T	p	Effect	Reason
decreases	constant	shift left	the forward reaction is endothermic ($\Delta H^\ominus > 0$), so the reverse reaction will produce extra heat to partly compensate the decrease in temperature
constant	increases	none	the total number of gas molecules on the left (reactant side) is the same as that on the right (product side)

(ii)



Note that all labels are required and the potential energy of the products must be higher than that of the reactants (as $\Delta H^\ominus > 0$).

(e) (i) *Oxidizing agent:* Iodine(I) bromide, IBr(s) .

Reducing agent: Sodium thiosulfate, $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$. The answers “thiosulfate ions” or “ $\text{S}_2\text{O}_3^{2-}$ ” will also be accepted.

Note that iodine(I) bromide gains electrons while sodium thiosulfate loses electrons.

(ii) $n(\text{IBr}) = 3.10 \text{ g} / 206.80 \text{ g mol}^{-1} \approx 0.0150 \text{ mol}$

$n(\text{Na}_2\text{S}_2\text{O}_3) = 2 \times n(\text{IBr}) = 2 \times 0.0150 \text{ mol} = 0.0300 \text{ mol}$

$V(\text{Na}_2\text{S}_2\text{O}_3) = 0.0300 \text{ mol} / 0.100 \text{ mol dm}^{-3} = 0.300 \text{ dm}^3$

3. (a) (i) $\text{MgCO}_3(\text{s}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{MgSO}_4(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$

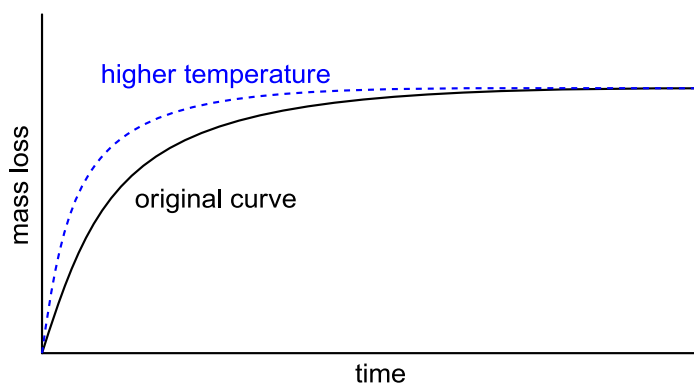
$\text{MgCO}_3(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow \text{Mg}^{2+}(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$

Either molecular or ionic equation (involving H^+ or H_3O^+) will score the mark.

Note that carbonic acid, $\text{H}_2\text{CO}_3(\text{aq})$, is unstable and thus will not be accepted as the reaction product.

(ii) As $\text{MgCO}_3(\text{s})$ reacts with the acid, its quantity decreases, and so does its surface area. The decreasing surface area reduces the number of successful collisions between the reactants, so the reaction rate decreases.

(iii)



Note that the curve for a higher temperature must flatten out at the same level as the original curve, as temperature does not affect the quantities of reactants and thus the final mass loss.

(b) (i) Relative uncertainty = $\sqrt{\sum \left(\frac{\Delta A}{A}\right)^2} = \sqrt{\left(\frac{0.1}{1.8}\right)^2 + \left(\frac{0.1}{1.8}\right)^2} \approx 0.08$ or 8%

- (ii) According to sections 1 of the data booklet, $q = mc\Delta T$. We can assume that dilute sulfuric acid is almost pure water ($\rho = 1.00 \text{ g cm}^{-3}$ and $c = 4.18 \text{ J g}^{-1} \text{ K}^{-1}$) and the heat capacity of the solid sample is negligible. In such a case:

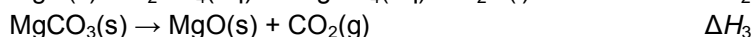
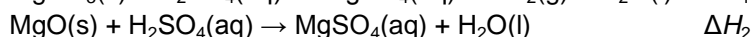
$$m_1 = m_2 = 100 \text{ cm}^3 \times 1.00 \text{ g cm}^{-3} = 100 \text{ g}$$

$$\Delta T_1 = 1.8 \text{ K}, \Delta T_2 = 29.6 - 21.5 = 8.1 \text{ K}$$

$$q_1 = 100 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times 1.8 \text{ K} \approx 750 \text{ J} = 0.75 \text{ kJ}$$

$$q_2 = 100 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times 8.1 \text{ K} \approx 3400 \text{ J} = 3.4 \text{ kJ}$$

- (iii) The difference between q_1 and q_2 is due to the heat absorbed by the decomposition of magnesite:



To obtain the third equation, we need to subtract the second equation from the first. According to the Hess's Law, $\Delta H_3 = \Delta H_1 - \Delta H_2$. Therefore:

$$n(\text{MgCO}_3) = 2.00 \text{ g} / 84.32 \text{ g mol}^{-1} \approx 0.0237 \text{ mol}$$

$$\Delta H_1 = -0.75 \text{ kJ} / 0.0237 \text{ mol} \approx -31.6 \text{ kJ mol}^{-1}$$

$$n(\text{MgO}) = n(\text{MgCO}_3) = 0.0237 \text{ mol}$$

$$\Delta H_2 = -3.4 \text{ kJ} / 0.0237 \text{ mol} \approx -143 \text{ kJ mol}^{-1} \text{ (minus signs used as both reactions are exothermic)}$$

$$\Delta H_3 = -31.6 \text{ kJ mol}^{-1} - (-143 \text{ kJ mol}^{-1}) \approx 111 \text{ kJ mol}^{-1}$$

- (iv) **Accuracy:** Heat loss to the environment, difference in heat capacity of the solution from that of pure water, non-zero heat capacities of the solid, thermometer and calorimeter, evaporation of water during the reaction, purity of starting materials, incomplete decomposition of magnesite.

Precision: Number of repetitions of the experiment(s), number of significant figures recorded by the student, random variations in the ambient temperature, masses of the samples and volumes of the solutions.

To score the full mark, you answer should include any **one** factor from each list. You can also refer to the accuracy and precision of the laboratory equipment (balance, measuring cylinder and thermometer) used in the experiments.

- (v) **Accuracy:** Use several nested coffee cups; cover the cup(s) with a heat-insulating material; use a smaller thermometer; determine the heat capacities of the thermometer, calorimeter and solid samples and take them into account in calculations; use an analytical-grade calorimeter instead of the coffee-cup calorimeter; use a purer sample of magnesite.

Precision: Repeat each of the experiments several times and average the results; use an analytical pipette, burette or volumetric flask instead of a measuring cylinder when adding dilute sulfuric acid to the calorimeter; use a more precise analytical balance; use a precise digital thermometer instead of the glass thermometer; run all experiments at a constant ambient temperature; record as many significant figures for each measurement as given by the laboratory equipment; keep extra significant figures in intermediate results and round only the final result to the correct number of significant figures.

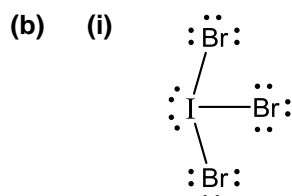
Similar to part (iv), you answer should include any **one** factor from each list.

4. (a) 3-methylbutan-1-ol
- (b) Acidified potassium dichromate or acidified potassium permanganate under reflux.
Note that the words "acidified" and "reflux" are required for mark.
- (c) $(\text{CH}_3)_2\text{CHCH}_2\text{COOH} + \text{CH}_3\text{OH} \xrightleftharpoons{\text{H}^+} (\text{CH}_3)_2\text{CHCH}_2\text{COOCH}_3 + \text{H}_2\text{O}$
- (d) $(\text{CH}_3)_2\text{CHCH}_2\text{COO}^-$
- (e) Your answer may include any **one** of the techniques outlined below.
- Prepare a 0.1 mol dm^{-3} solution of the studied acid and measure its pH. If $\text{pH} = 1$, the acid is strong; if $\text{pH} > 1$, the acid is weak.
(For a 0.01 mol dm^{-3} solution, the pH will be 2 for a strong acid and greater than 2 for a weak acid.)
 - Prepare two solutions, one of the studied acid and another of a known acid with the same concentration. Then measure the pH values of both solutions. If $\text{pH}_1 < \text{pH}_2$, then the studied acid is stronger than the known acid; otherwise, it is weaker.
 - Same as above, but measure the conductivities of both solutions. If the first solution has a higher conductivity than the second, the studied acid is stronger than the known acid; otherwise, it is weaker.
 - Titrate a solution of the studied acid with a strong base. If at the equivalence point $\text{pH} = 7$, the acid is strong; otherwise, it is weak. For a weak acid at the half-equivalence point, $\text{pH} = \text{p}K_a$. The lower the $\text{p}K_a$, the stronger the acid.
 - Prepare two solutions, one of the studied acid and another of a known acid with the same concentration. Then add equal quantities of an active metal, metal oxide, metal carbonate or metal hydrogencarbonate to each of the solutions. The acid that reacts faster is the strongest of the two.
 - Determine the enthalpy of neutralization of the studied acid. The greater (more negative) the enthalpy, the stronger the acid.

5. (a) (i) $K_c = \frac{[\text{I}_2][\text{Br}_2]}{[\text{IBr}]^2}$
- (ii) $T = 135 + 273 = 408 \text{ K}$
 $\Delta G^\circ_{\text{decomp}}(\text{IBr}) = 7.2 \text{ kJ mol}^{-1} = 7200 \text{ J mol}^{-1}$
 The reaction involves two moles of IBr, so the ΔG° value for the reaction is $2 \times 7200 \text{ J mol}^{-1} = 14400 \text{ J mol}^{-1}$.
 According to section 1 of the data booklet, $\Delta G^\circ = -RT \ln K_c$, so:

$$\ln K_c = -\frac{14400 \text{ J mol}^{-1}}{8.31 \text{ J K}^{-1} \text{ mol}^{-1} \times 408 \text{ K}} \approx -4.25$$

$$K_c = e^{-4.25} \approx 0.014$$



Each bonding and lone electron pair can be represented by either two dots or a line.

- (ii) *Electron domain geometry*: trigonal bipyramidal (as there are five electron domains around the iodine atom, including three bonding electron pairs and two lone electron pairs).
Molecular geometry: T-shaped (as both lone electron pairs occupy equatorial positions to minimize the mutual repulsion between the electron domains).
- (iii) Less than 90° for $\text{Br}_{\text{ax}}\text{--I--Br}_{\text{eq}}$ and less than 180° for $\text{Br}_{\text{ax}}\text{--I--Br}_{\text{ax}}$.
- (c) According to the Lewis theory of acids and bases, this is a neutralization reaction. The Lewis base IBr donates one of its lone electron pairs to the empty electron orbital of the Lewis acid FeBr_3 .
- (d) (i)
$$\text{H}_2\text{C}=\text{CH--CH}_3 + \text{IBr} \longrightarrow \begin{array}{c} \text{H}_2\text{C} \text{---} \text{CH} \text{---} \text{CH}_3 \\ | \quad | \\ \text{I} \quad \text{Br} \end{array}$$
- Note that iodine has lower electronegativity than bromine, so it has a partial positive charge (δ^+) and thus adds to the double bond first, producing the secondary carbocation, $\text{H}_2\text{C(I)--CH}^+\text{--CH}_3$, which then reacts with the leaving group, Br^- , and forms the main organic product, 2-bromo-1-iodopropane.
- (ii) *Propene*: sp^2 ; *organic product*: sp^3 .
6. (a) (i) The slope of the tangent line to the curve at $t = 0$ will give the reaction rate (in g of $\text{CO}_2(\text{g})$ released from the mixture per second). To calculate the rate in $\text{mol dm}^{-3} \text{s}^{-1}$, we need to divide the slope by $M(\text{CO}_2) = 44.01 \text{ g mol}^{-1}$ and by the volume of the solution (in dm^3).
- (ii) The concentration of $\text{H}^+(\text{aq})$ ions is proportional to the concentration of sulfuric acid:
 $\text{H}_2\text{SO}_4(\text{aq}) \rightarrow 2\text{H}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq})$
 When $c(\text{H}_2\text{SO}_4)$ doubles, the initial rate also doubles, so the reaction is first order with respect to $\text{H}^+(\text{aq})$ ions.
- (iii) According to section 1 of the data booklet, $\ln \frac{k_1}{k_2} = \frac{E_a}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$. Since the concentrations of sulfuric acid in experiments 1 and 3 were identical, $\frac{k_1}{k_3} = \frac{v_1}{v_3}$.
 Therefore:
 $T_1 = 21.4 + 273 = 294.4 \text{ K}$
 $T_3 = 35.2 + 273 = 308.2 \text{ K}$

$$\ln \frac{1.65 \times 10^{-4} \text{ mol dm}^{-3} \text{s}^{-1}}{5.22 \times 10^{-4} \text{ mol dm}^{-3} \text{s}^{-1}} = \frac{E_a}{8.31 \text{ J K}^{-1} \text{mol}^{-1}} \left(\frac{1}{308.2 \text{ K}} - \frac{1}{294.4 \text{ K}} \right)$$

$$\ln(0.316) = \frac{E_a}{8.31 \text{ J K}^{-1} \text{mol}^{-1}} (-0.000152 \text{ K}^{-1})$$

$$E_a \approx 6.30 \times 10^4 \text{ J mol}^{-1} = 63.0 \text{ kJ mol}^{-1}$$
- (iv) Your answer may include any **one** of the following: degree of dispersion/surface area of magnesite; purity of magnesite; rate/method of stirring.
- (b) According to section 12 of the data booklet, $\Delta S^\circ(\text{CO}_2(\text{g})) = 213.8 \text{ J K}^{-1} \text{mol}^{-1}$.
 Therefore:
 $\Delta S^\circ_{\text{decomp}}(\text{MgCO}_3(\text{s})) = 27.0 + 213.8 - 65.7 = +175.1 \text{ J K}^{-1} \text{mol}^{-1}$
- (c) According to section 1 of the data booklet, $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$. The decomposition will become favourable when $\Delta G^\circ < 0$. Therefore:
 $111 \text{ kJ mol}^{-1} - T \times 0.1751 \text{ kJ K}^{-1} \text{mol}^{-1} < 0$
 (Note that ΔS° has been converted to $\text{kJ K}^{-1} \text{mol}^{-1}$ because ΔH° is expressed in kJ mol^{-1} .)
 $111 < T \times 0.1751 \text{ K}^{-1}$
 $T > 634 \text{ K}$

Therefore, the decomposition will become favourable at $T > 634 - 273 = 361^\circ\text{C}$.
(If you used $\Delta H^\circ = 100 \text{ kJ mol}^{-1}$ and $\Delta S^\circ = 200 \text{ J K}^{-1} \text{ mol}^{-1}$, your answer should be $T > 227 \text{ K}$).

- (d) Both MgO(s) and CaO(s) are ionic compounds, so their lattices consist of doubly charged cations and doubly charged anions. However, Mg is higher in group 2 of the periodic table than Ca, so the ionic radius of Mg^{2+} is smaller than that of Ca^{2+} . The smaller cations Mg^{2+} will experience a stronger electrostatic attraction to O^{2-} anions, so the ionic bonding in MgO(s) will be stronger than that in CaO(s) . Therefore, the lattice enthalpy of MgO(s) (3791 kJ mol^{-1}) is greater than the lattice enthalpy of CaO(s) (3401 kJ mol^{-1}).

7. (a) $\text{KOH(aq)} \rightarrow \text{K}^+(\text{aq}) + \text{OH}^-(\text{aq})$
 $[\text{OH}^-] = 0.0100 \text{ mol dm}^{-3}$

$$[\text{H}^+] = \frac{K_w}{[\text{OH}^-]} = \frac{1.00 \times 10^{-14}}{0.0100} = 1.00 \times 10^{-12} \text{ mol dm}^{-3}$$

 $\text{pH} = -\log[\text{H}^+] = -\log(1.00 \times 10^{-12}) = 12.00$

Alternative solution:

$$\text{pOH} = -\log[\text{OH}^-] = -\log(0.0100) = 2.00$$

$$\text{pH} = 14 - \text{pOH} = 14 - 2.00 = 12.00$$

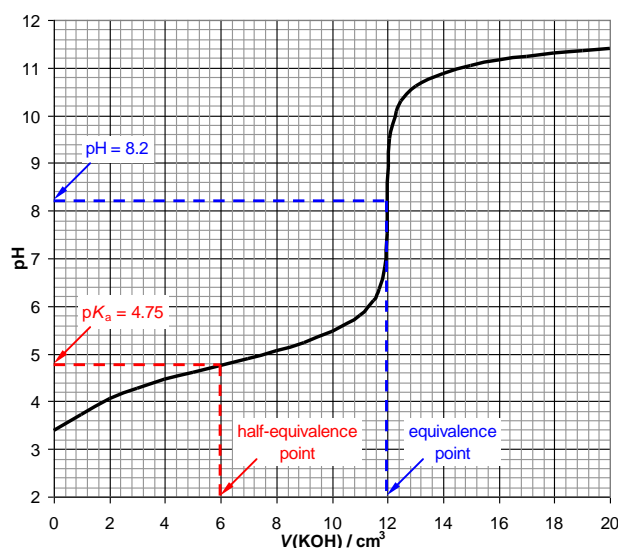
- (b) The pH at the equivalence point is approximately 8.2 (see part (e)), so the best indicator is phenol red ($\text{p}K_a = 7.9$). Two other indicators, bromothymol blue ($\text{p}K_a = 7.0$) and phenolphthalein ($\text{p}K_a = 9.6$), can also be used, as their $\text{p}K_a$ values are within the pH jump of the titration curve.

- (c) The equivalence point is reached at $V(\text{KOH}) = 12.0 \text{ cm}^3 = 0.0120 \text{ dm}^3$, so:
 $n(\text{KOH}) = 0.0100 \text{ mol dm}^{-3} \times 0.0120 \text{ dm}^3 = 1.20 \times 10^{-4} \text{ mol}$

- (d) $\text{HA(aq)} + \text{KOH(aq)} \rightarrow \text{KA(aq)} + \text{H}_2\text{O(l)}$
 $n(\text{HA}) = n(\text{KOH}) = 1.20 \times 10^{-4} \text{ mol}$
 $m(\text{HA}) = 5.52 \text{ mg} = 5.52 \times 10^{-3} \text{ g}$

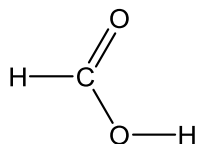
$$M(\text{HA}) = \frac{5.52 \times 10^{-3} \text{ g}}{1.20 \times 10^{-4} \text{ mol}} = 46.0 \text{ g mol}^{-1}$$

- (e) The $\text{p}K_a$ of the acid is equal to the pH value at the half-equivalence point:



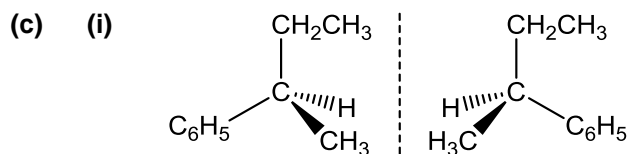
Note that the equivalence point is reached at $V(\text{KOH}) = 12.0 \text{ cm}^3$, so the half-equivalence point is reached at $V(\text{KOH}) = 6.0 \text{ cm}^3$. The acceptable range for $\text{p}K_a$ values is 4.7–4.8.

(f)



Note that a condensed formula, such as HCOOH, will not be accepted, as a full structural formula is required.

8. (a) At higher frequencies, the emission or absorption lines in the line spectrum of titanium become closer to one another and eventually converge.
The IE_1 of titanium can be found from the formula $IE_1 = h\nu$, where h is the Planck's constant and ν is the frequency at the limit of convergence.
- (b) (i) The oxidation state of titanium is +3 in the first ion and +4 in the second ion. Note that the answers "3+" and "4+" would not be accepted.
(ii) The first ion, $[\text{Ti}(\text{H}_2\text{O})_6]^{3+}$, is coloured because the central atom in this ion has one 3d electron (while in the second ion it has none). The energy of electron transitions within the 3d sublevel corresponds to the frequency of visible light.
(iii) Note that the units given in the question are incorrect – they should be nm, not cm^{-1} .
The wavelength 580 nm corresponds to yellow light. If yellow light is absorbed, the light of the complementary colour (violet) is transmitted, so the complex appears violet.
Note that in reality this complex appears purple rather than violet, as the absorption at 580 nm is very broad and covers the range from 500 to 640 nm. As a result, the complex absorbs not only yellow but also green and orange light. The complementary colours to green and orange are red and blue, respectively. The combination of red, blue and violet light produces the characteristic purple colour of Ti(III) complexes.
9. (a) $2\text{Ag}^+(\text{aq}) + \text{Ni}(\text{s}) \rightarrow 2\text{Ag}(\text{s}) + \text{Ni}^{2+}(\text{aq})$
(b) $\text{Ni}(\text{s}) \mid \text{Ni}^{2+}(\text{aq}) \parallel \text{Ag}^+(\text{aq}) \mid \text{Ag}(\text{s})$
(c) According to section 24 of the data booklet, $E^\circ(\text{Ni}(\text{s})/\text{Ni}^{2+}(\text{aq})) = -0.26 \text{ V}$ and $E^\circ(\text{Ag}(\text{s})/\text{Ag}^+(\text{aq})) = +0.80 \text{ V}$. Therefore, $E^\circ_{\text{cell}} = +0.80 \text{ V} - (-0.26 \text{ V}) = 1.06 \text{ V}$. Note that the answer "–1.06 V" would not be accepted, as the cell potential for a spontaneous process must be positive.
(d) As any redox process, the reaction given in part (a) is reversible:
 $2\text{Ag}^+(\text{aq}) + \text{Ni}(\text{s}) \rightleftharpoons 2\text{Ag}(\text{s}) + \text{Ni}^{2+}(\text{aq})$
According to Le Châtelier's principle, an increase in the concentration of the product, $\text{Ni}^{2+}(\text{aq})$, favours the reverse reaction and thus makes the forward reaction less spontaneous. Therefore, the cell potential will decrease.
The same conclusion based on the Nernst equation (Topic C.6) would also be accepted, although this equation is not a part of the core syllabus.
10. (a) Your answer may include the discussion any **two** techniques outlined in table 10.1.4.
(b) $\text{C}_6\text{H}_6 + \text{HNO}_3 \rightarrow \text{C}_6\text{H}_5\text{NO}_2 + \text{H}_2\text{O}$
Conditions: a mixture of concentrated nitric and concentrated sulfuric acids **and** heat.



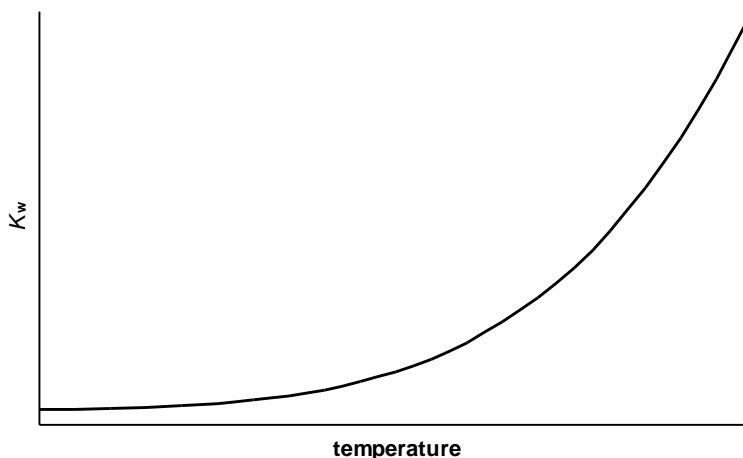
Fisher projections would also be accepted.

- (ii) Four signals with the integration ratio 1 : 2 : 3 : 3.
 Note that the protons of CH_3 groups in the CH_2CH_3 and CHCH_3 fragments are in different chemical environments, so they will produce two signals, not one.
- (iii) Bromine water (but-1-ene will decolourize it while the reaction product will not).

Paper 3

SECTION A

1. (a) $\text{pH} = 6.89$.
 The acceptable range of answers is from 6.88 to 6.90. Note that the distance between minor gridlines is 2°C on the x-axis and 0.04 pH units on the y-axis.
- (b) $[\text{H}^+] = 10^{-\text{pH}} = 10^{-6.89} \approx 1.29 \times 10^{-7} \text{ mol dm}^{-3}$
 In pure water, $[\text{OH}^-] = [\text{H}^+]$, so:
 $K_w = [\text{H}^+][\text{OH}^-] = (1.29 \times 10^{-7} \text{ mol dm}^{-3})^2 \approx 1.66 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$
 $\text{p}K_w = -\log K_w = -\log(1.66 \times 10^{-14}) \approx 13.78$
Alternative solution:
 $\text{p}K_w = \text{pH} + \text{pOH}$. In pure water, $\text{pH} = \text{pOH}$, so $\text{p}K_w = 6.89 + 6.89 = 13.78$
- (c) To score the full mark, both axes in your sketch must be labelled, and the curve must look similar to the one shown below, although it does not have to be drawn to scale.



Note that the K_w values at different temperature are given in section 23 of the data booklet.

- (d) $\text{H}_2\text{O(l)} \rightleftharpoons \text{H}^+(\text{aq}) + \text{OH}^-(\text{aq})$
 An equation with $\text{H}_3\text{O}^+(\text{aq})$ instead of $\text{H}^+(\text{aq})$ is also acceptable.
- (e) The sketch in part (c) shows a positive correlation: as temperature increases, the K_w value also increases. If K_w increases, then both $[\text{H}^+]$ and $[\text{OH}^-]$ also increase. Therefore, an increase in temperature shifts the position of the equilibrium in part (d) to the right (towards products). This is possible only for an endothermic process, so $\Delta H^\ominus > 0$.

2. (a) To score the first of the two marks, you need to mention any **one** of the following:
- measure the volume of gas released during the reaction / use a gas syringe / use an overturned measuring cylinder filled with water;
 - measure the mass (or mass loss) of the mixture / place the reaction vessel on an analytical balance;
 - measure the pH of the solution / use a pH probe;
 - measure the conductivity of the solution / use a conductivity probe;
 - plot the volume/mass (loss)/pH/conductivity as a function of time.
- To score the second mark, you need to state that the initial rate can be determined from the slope of the tangent to the curve at $t = 0$.
- (b) $n_1(\text{HCl}) = 0.0500 \text{ dm}^3 \times 1.00 \text{ mol dm}^{-3} = 0.0500 \text{ mol}$
 $n_2(\text{HCl}) = 0.0500 \text{ dm}^3 \times 2.00 \text{ mol dm}^{-3} = 0.100 \text{ mol}$
 $n_1(\text{Zn}) = 1.00 \text{ g} / 65.38 \text{ g mol}^{-1} \approx 0.0153 \text{ mol}$
 $n_2(\text{Zn}) = 10.0 \text{ g} / 65.38 \text{ g mol}^{-1} \approx 0.153 \text{ mol}$
- The second method would be least affected, as zinc was taken in excess, so any variations in its mass would only slightly affect the reaction time (due to slight differences in the surface area). In the first method, zinc was the limited reactant, so any variations in its mass would directly affect the reaction time.
- (c) Any **one** of the following: surface area, degree of dispersion, particle size, purity.
- (d) A larger surface area, a higher degree of dispersion or a smaller particle size will accelerate the reaction (due to the increased number of collisions between the reactant particles). The lower purity can either slow down the reaction (if the impurity is less reactive than zinc) or accelerate the reaction (if the impurity is more reactive than zinc).
- (e) No, it is not appropriate, as the differences between individual measurements and their average value are much greater than 0.1 s.
- (f) Approximately 80 s.
 Note that in reality the average time will be slightly less than 80 s, as the concentration of the $2.00 \text{ mol dm}^{-3} \text{ HCl(aq)}$ will decrease during the reaction by a smaller proportion than that of the $1.00 \text{ mol dm}^{-3} \text{ HCl(aq)}$. However, you do not have to state this to score the mark.
- (g) Systematic error, as in all cases the stopwatch was started later than needed, so the recorded reaction times were consistently shorter than the actual reaction times.

SECTION B

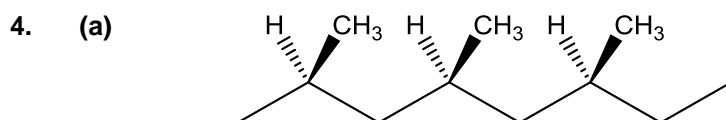
Option A

3. (a) A composite is a heterogeneous material that consists of two distinct phases: a matrix phase embedded into a reinforcing phase. Ceramic materials are typically homogeneous and consist of a single inorganic phase where the constituent elements form a giant ionic or covalent lattice.
- (b) According to section 8 of the data booklet, the electronegativity values of Zr and O are 1.3 and 3.4, respectively. The average electronegativity is $(1.3 + 3.4)/2 \approx 2.4$, and the electronegativity difference is $3.4 - 1.3 = 2.1$. According to section 29 of the data booklet, the bond is ionic.
- (c) Because zirconium is more active than both carbon and hydrogen.

- (d) Your answer should include at least **one** similarity and **two** differences, which are outlined in the table below.

	Homogeneous catalysts	Heterogeneous catalysts
similarities	increase the reaction rate / speed up the reaction; lower the activation energy; provide an alternative pathway for a reaction	
differences	distribute through the whole volume of the reaction mixture; chemically combine with reactants; form intermediates or transition states with reactants; detach and release products	provide a surface for the reaction to occur; adsorb reactants onto active sites; bring reactants into correct mutual position and orientation to react; allows products to desorb

- (e) (i) Plasma is a state of matter that consists of isolated atoms or small molecules, cations and electrons. In other words, it is a partly or completely ionized gas.
- (ii) To score the full mark, your answer should include any **two** of the following:
- argon/carrier gas passes through a quartz tube with an external electric coil;
 - an alternating electric current in the coil creates an oscillating magnetic field inside the tube;
 - the magnetic field distorts electron orbitals in argon;
 - some argon atoms lose their outer electrons / become ionized.



Note that all CH₃ groups are on the same side of the hydrocarbon chain. A more detailed structural formula that shows all carbon and hydrogen atoms is also acceptable.

- (b) The molecules of plasticizers keep the hydrocarbon chains apart and thus reduce the strength of intermolecular London dispersion forces. As a result, plasticizers reduce the density, hardness and mechanical strength of polypropylene, making it more flexible and permeable to gases and certain liquids.
- (c) Your answer may include any **two** of the following: use of non-renewable resources (fossil fuels) as starting materials; use of toxic/hazardous chemicals as catalysts; low biodegradability; choking/entanglement hazard to animals; release of carbon dioxide/greenhouse gases when polypropylene is combusted; use of land for the disposal of polypropylene in landfills; leaching of biologically active plasticizers into the environment.
- (d) Your answer may include any **one** of the following: to preserve the value of material (as mixed plastics have unpredictable/variable properties); to keep thermoplastic and thermosetting plastics apart from each other (for further processing); to allow the recycling of materials that are already made from recycled plastics; to prevent the release of ozone-depleting agents, dioxins and other toxic substances when recycled materials are combusted (this may happen when RIC-3 plastic, PVC, is mixed with other plastics).

5. (a) Rod-shaped.

- (b) The polarity enables the molecule to change its orientation in an external electric field. This allows you to control the brightness of individual pixels in an LCD by applying electric potentials to specific areas of the display.
The long hydrocarbon chains prevent close packing of the molecules but contribute to their overall rod-shaped configuration, thus allowing the molecules to align with one another. At the same time, the hydrocarbon chains reduce the melting point of LCs, allowing them to exist in LC state at room temperature.
- (c) *Catalyst*: iron nanoparticles, which are formed by the thermal decomposition of iron(0) pentacarbonyl, $\text{Fe}(\text{CO})_5$.
Conditions: high pressure **and** high temperature.
- (d) Any **one** of the following: specific health concerns (allergies, weakening of the immune system, cancer, irritation of the respiratory system); unknown long-term effects on human health; unknown effects on the environment; lack of information for consumers (such as labelling the products containing nanoscale materials).
6. (a) Your answer should include at least **one** similarity and **two** differences, which are outlined in the table below.

	Type 1 semiconductors	Type 2 semiconductors
similarities	have zero electrical resistance under certain conditions; expel magnetic field; demonstrate Meissner effect	
differences	sharp transition to superconductivity; lower critical temperature; have one critical magnetic field; usually pure metals;	gradual transition to superconductivity; higher critical temperature; have two critical magnetic fields; alloys/ceramics/oxides/composites;

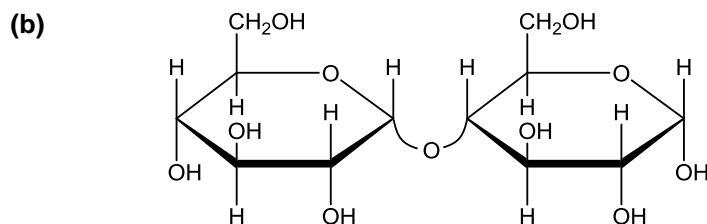
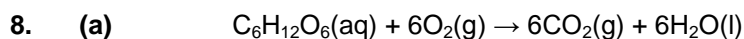
- (b) $m(\text{unit cell}) = 6 \times 91.22 \text{ amu} \times 1.66 \times 10^{-27} \text{ kg amu}^{-1} \approx 9.086 \times 10^{-25} \text{ kg} = 9.086 \times 10^{-22} \text{ g}$
 $V(\text{unit cell}) = 0.1394 \text{ nm}^3 = 1.394 \times 10^{-22} \text{ cm}^3$
 $\rho(\text{Zr}) = \frac{9.086 \times 10^{-22} \text{ g}}{1.394 \times 10^{-22} \text{ cm}^3} \approx 6.52 \text{ g cm}^{-3}$
 The answer must be rounded to three significant figures.
7. (a) Hydrogen chloride, HCl. The answer "2HCl" will also be accepted.
- (b) The reaction can be represented as follows (the M_r values are shown under the molecular formulas):

$$\begin{array}{ccccccc} 2\text{C}_2\text{H}_8\text{N}_2 & + & 2\text{C}_4\text{H}_8\text{Cl}_2\text{O} & \rightarrow & \text{C}_{12}\text{H}_{28}\text{N}_4\text{O}_2 & + & 4\text{HCl} \\ 60.12 & & 143.02 & & 260.44 & & 36.46 \end{array}$$

 From every $2 \times 60.12 + 2 \times 143.02 = 406.28 \text{ amu}$ of atoms used, 260.44 amu of atoms ends up in the target product. Therefore:

$$\%(\text{atom economy}) = \frac{260.44 \text{ amu}}{406.28 \text{ amu}} \times 100\% \approx 64.10\%$$
- (c) Each chelate ligand forms several coordinate bonds with a metal ion. The greater the number of bonds, the more energy is required to break these bonds. In addition, the formation of chelate complexes in aqueous solutions releases many molecules of water, which were initially bound to metal ions and free chelate ligands. This increases the entropy of the system. Because of these two factors, collectively known as the chelate effect, chelate complexes form readily and do not dissociate easily. In other words, chelate ligands greatly reduce the concentration of free metal ions in solutions.

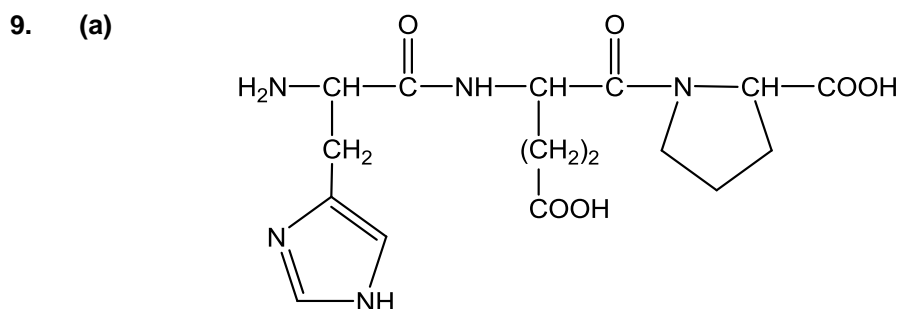
Option B



(c) In a condensation reaction, two or more reactant molecules form one larger molecule (target product) and one or more smaller, usually inorganic molecules (by-product). In a hydrolysis reaction, one large molecule reacts with one or more molecules of water to form two or more smaller molecules.

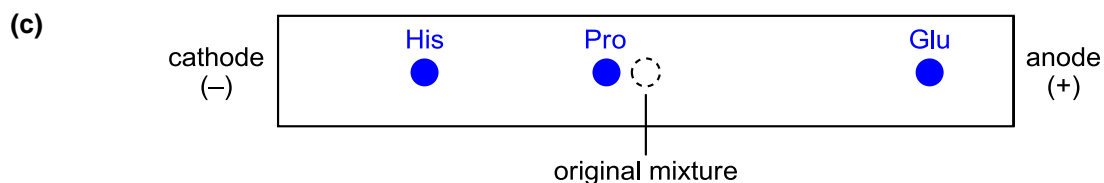
(d) *Advantages:* renewable/sustainable; can be broken down quickly by microorganisms; reduce volume of plastic waste/landfill; reduce use of fossil fuels (as hydrocarbon source); degrade into non-toxic products.

Disadvantages: require land (for plant growth); plants require fertilizers/pesticides (which leach to the environment); might break down before the end of use; release methane in landfills.



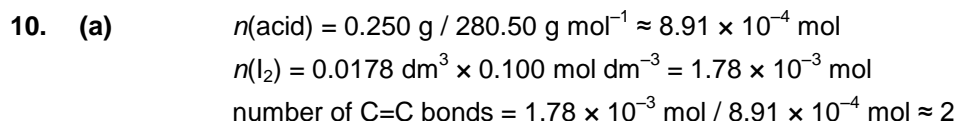
(b) High temperature **and** concentrated hydrochloric acid, $\text{HCl}(\text{aq})$.

Note that concentrated sulfuric or nitric acids cannot be used, as they will decompose (dehydrate and/or oxidize) the amino acids.



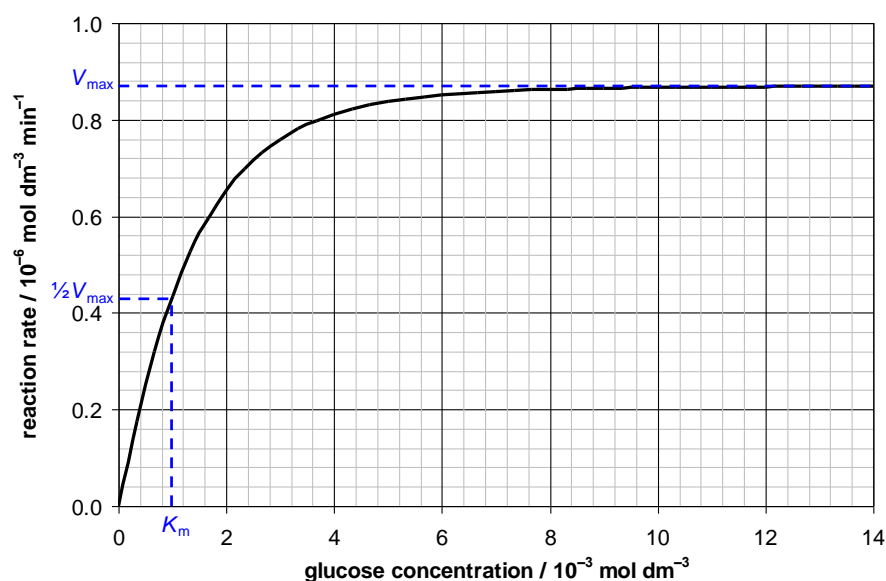
To score the full mark, you need to show the spots of both histidine (His) and proline (Pro) on the left, with histidine being further from the starting point than proline. The spot of glutamic acid (Glu) must be on the right.

Note that both proline ($\text{pI} = 6.3$) and histidine ($\text{pI} = 7.6$) will be partly protonated at $\text{pH} = 6.0$ and thus will move to the negative electrode. Proline will move slower than histidine, as its pI is very close to the pH , so its average positive charge will be very small. Glutamic acid ($\text{pI} = 3.2$) at $\text{pH} = 6.0$ will exist almost exclusively in its anionic form and thus move to the positive electrode.



- (b) Another common fatty acid with two C=C bonds is linoleic acid, $C_{17}H_{31}COOH$, or $C_{18}H_{32}O_2$ (see section 34 of the data booklet). The molecular mass of linoleic acid ($280.50 \text{ g mol}^{-1}$) is identical to that of rumenic acid, so rumenic acid must have the molecular formula $C_{18}H_{32}O_2$.
- (c) Because sucrose is more oxidized (has a higher proportion of oxygen to other elements) than rumenic acid. Therefore, a complete oxidation of sucrose to carbon dioxide and water would require less oxygen and thus will release less energy per gram.
Your answer can also be based on the average oxidation states of carbon in sucrose (0) and rumenic acid (approximately -1.56).
- (d) Stearic and rumenic acids have similar molecular masses. However, the C=C fragments in rumenic acid form kinks in the hydrocarbon chains, preventing the chains from packing closely and weakening the intermolecular London dispersion forces. Stearic acid has no C=C fragments, so the intermolecular forces between its molecules are stronger and thus its melting point is higher than that of rumenic acid.
The answer "stearic acid is saturated while rumenic acid is not" would score one point. The second point requires a reference to intermolecular forces and their nature.
11. (a) Because it has many polar functional groups that can form hydrogen bonds with water.
- (b) Because it is a natural product and thus is biodegradable. In addition, its oxidation product, $C_6H_6O_6$, is a weak acid while the oxidation product of SO_2 is H_2SO_4 , which is a strong acid and thus is likely to cause more damage to the environment.

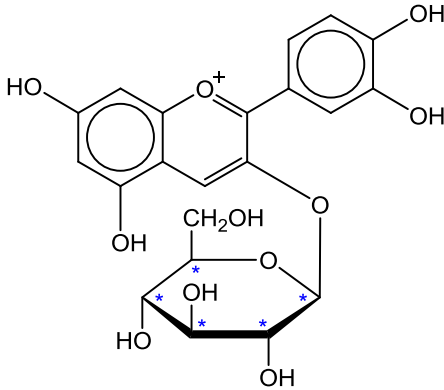
12. (a)



According to the diagram, $K_m \approx 1.0 \times 10^{-3} \text{ mol dm}^{-3}$.

Note that K_m is equal to the concentration of glucose at $\frac{1}{2} V_{max}$ and has the same units as that concentration.

- (b) It means that glucose-6-phosphate binds to hexokinase and reduces the activity of hexokinase.
Note that the answer "reaction product binds to enzyme and reduces its activity" would not score the mark, as references to specific product (glucose-6-phosphate) and enzyme (hexokinase) are required.

- (c) If K_m is not affected, glucose-6-phosphate is a non-competitive inhibitor. Therefore, it binds to an allosteric site.
- (d) –CTATTGCAT–
Note that DNA contains thymine (T) instead of uracil (U) in RNA.
- (e) Your answer may include any two differences that are outlined in table B.8.1.
13. (a)
- 
- Note that all five chiral carbon atoms are in the glucose residue.
- (b) They have extended systems of electron conjugation. The electron transitions in such systems have energies similar to those of photons of visible light.
- (c) At pH = 3, the maximum of absorbance is at ≈ 520 nm (green light). According to section 17 of the data booklet, the colour complementary to green is red. Therefore, at pH = 3, the juice appears red. Similarly, at pH = 11, the juice strongly absorbs light around 610 nm (orange) and thus appears blue, as blue is complementary to orange.
- (d) One of the C=C bonds in retinal changes its configuration from *cis*- to *trans*-.

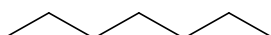
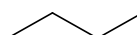

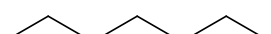

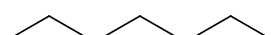
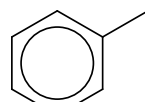
Option C

14. (a) According to section 13 of the data booklet, $\Delta H_c^\circ(\text{C}_2\text{H}_5\text{OH}) = -1367 \text{ kJ mol}^{-1}$.
Therefore:
 $M(\text{C}_2\text{H}_5\text{OH}) = 46.08 \text{ g mol}^{-1}$
specific energy = $\frac{-1367 \text{ kJ mol}^{-1}}{46.08 \text{ g mol}^{-1}} \approx 29.67 \text{ kJ g}^{-1} = 29.67 \text{ MJ kg}^{-1}$
- (b) Ethanol is less useful, as its specific energy is lower than that of gasoline. Therefore, more ethanol will be required for the vehicle to travel the same distance.
- (c) (i) Vegetable oils are very viscous and virtually non-volatile, so they would clog the engine if used without modification. Biodiesel has lower viscosity and higher volatility than vegetable oils.
- (ii) $\text{CH}_3(\text{CH}_2)_3(\text{CH}_2\text{CH}=\text{CH})_2(\text{CH}_2)_7\text{COOCH}_2\text{CH}_3$.
A more detailed structural formula would also be acceptable.
Note that the transesterification reaction also produces glycerol. However, glycerol is usually removed from the reaction mixture and thus it is not a part of biodiesel.

- (iv) *Advantages (any one will score the mark):* renewable; biodegradable; have lower carbon footprint than fossil fuels; can be produced from organic waste; can be produced in countries with limited fossil fuel resources.

Disadvantages (any one will score the mark): take up land (for growing crops); require fertilizers and pesticides; often produce more NO_x than fossil fuels; more expensive than fossil fuels; engines might need modification for running on biodiesel.

- (d) There are several possible answers, some of which are outlined in the table below. All reactions require high temperature and the presence of a catalyst.

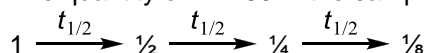
Method	Equation
catalytic cracking	 \longrightarrow  $+$ 
catalytic reforming	 \longrightarrow 
	 \longrightarrow  $+$ 4H_2

Other possible reaction products are straight-chain and branched alkanes (methane to pentane), alkenes (ethene to hexene), cycloalkanes and benzene.

15. (a) *Similarity:* in both fusion and fission reactions, the products have higher binding energy per nucleon than the reacting species.
Difference: in fusion, two light nuclei combine together and form a heavier nucleus (and sometimes other products); in fission, one heavy nucleus produces two lighter nuclei (and several neutrons).

- (b) $A = 259 + 5 \times 1 - 242 = 22$
 $Z = 104 + 5 \times 0 - 94 = 10$
 The nuclide with $Z = 10$ is neon (Ne).
 Therefore, ${}^A_Z\text{X}$ is ${}^{22}_{10}\text{Ne}$.

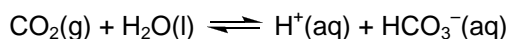
- (c) The quantity of Rf-259 in the sample decreases as follows:



The decay to $\frac{1}{8}$ of the initial quantity takes three half-lives, so $t_{1/2} = \frac{9.6 \text{ s}}{3} = 3.2 \text{ s}$.

16. **A:** UV; **B:** visible; **C:** IR; **D:** IR.
 For **C**, the answer "visible and IR" will also be accepted.
 Any **two** correct answers will score one mark.

17. Carbon dioxide dissolves in water to produce protons and hydrogencarbonate ions:



The increasing concentration of $\text{CO}_2(\text{g})$ shifts the above equilibrium to the right, increasing $[\text{H}^+]$ and thus decreasing the pH of oceanic water.

18. (a) *Anode:* $\text{CH}_3\text{OH}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{CO}_2(\text{g}) + 6\text{H}^+(\text{aq}) + 6\text{e}^-$
Cathode: $\text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}(\text{l})$

- (b) To score the full mark, you need to mention any **one** advantage and any **one** disadvantage, which are outlined below.
- Advantages:* can be used continuously (do not need to be recharged); has high specific energy and thermodynamic efficiency; does not contain toxic lead compounds.
- Disadvantages:* expensive; needs constant supply of fuel; uses toxic and flammable fuel (methanol); works well only when hot; produces a greenhouse gas (carbon dioxide); electrodes can be poisoned by impurities in the fuel.
19. (a) Uranium hexafluoride has a simple molecular lattice, where individual UF_6 molecules are held together by weak London dispersion forces. In contrast, uranium dioxide has a giant ionic lattice, where individual U^{4+} and O^{2-} ions are held together by strong electrostatic attraction forces (ionic bonding). The stronger the forces in the lattice, the higher the boiling point.
- (b) According to sections 2 and 4 of the data booklet, $1 \text{ amu} = 1.66 \times 10^{-27} \text{ kg}$ and $m({}_0^1\text{n}) = 1.674927 \times 10^{-27} \text{ kg}$. Therefore:
- $$m({}_0^1\text{n}) = \frac{1.674927 \times 10^{-27}}{1.66 \times 10^{-27}} \approx 1.00899 \text{ amu}$$
- $$\Delta m(\text{per 1 atom of } {}^{235}\text{U}) = 235.04393 + 1.00899 - 136.90709 - 95.93427 - 3 \times 1.00899 = 0.18459 \text{ amu}$$
- $$\Delta m(\text{per 1 mol of } {}^{235}\text{U}) = 0.18459 \text{ amu} \times 1.66 \times 10^{-27} \text{ kg amu}^{-1} \times 6.02 \times 10^{23} \approx 1.84 \times 10^{-4} \text{ kg}$$
20. (a) Any **two** of the following: both have extended systems of electron conjugation/delocalization; both contain a metal ion / both are metal complexes; both contain a polydentate ligand; in both complexes nitrogen atoms act as Lewis bases.
- (b) The darker the colour, the more visible light is absorbed. In other words, any dark-coloured substance absorbs photons across the whole spectrum of visible light. Therefore, the deep brown or black colour of the dye increases its efficiency in absorbing solar radiation.

Option D

21. (a) Mild analgesics act at the source of pain/injury by interfering with the production of pain-sensitizing substances (prostaglandins).
- (b) Aspirin can be converted into a soluble aspirin by the reaction with a base, for example:
- $$\text{CH}_3\text{C}(\text{O})\text{OC}_6\text{H}_4\text{COOH}(\text{s}) + \text{NaOH}(\text{aq}) \rightarrow \text{CH}_3\text{C}(\text{O})\text{OC}_6\text{H}_4\text{COONa}(\text{aq}) + \text{H}_2\text{O}(\text{l})$$
- An ionic equation can be written instead of the molecular equation. Other bases, such as KOH , Na_2CO_3 or NaHCO_3 , are also acceptable.
- (c) (i) Opiates bind to opioid receptors in the brain/CNS and block the transmission of pain impulses from the source of pain to the brain.
- (ii) Iodomethane, CH_3I , in the presence of a base, such as KOH . Any other methylating reagent is also acceptable.
- (iii) Codeine, as it is less polar than morphine and thus is more soluble in lipid-based blood-brain barrier.
- (iv) Codeine is less potent than morphine and thus poses a lower risk of overdose. Note that the answer "codeine is less addictive" is incorrect.

22. The beta-lactam ring is strained due to its unusual bond angles (90° instead of 109.5° for sp^3 -hybrid atoms and 120° for sp^2 -hybrid atoms) and thus is very reactive. In bacteria, this ring opens and binds irreversibly to transpeptidase, the enzyme responsible for cross-linking of bacterial cell walls.

23. (a) $\text{CO}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{HCO}_3^-(\text{aq})$
In this equation, the system $\text{CO}_2(\text{aq}) + \text{H}_2\text{O}(\text{l})$ acts as the conjugate acid while $\text{HCO}_3^-(\text{aq})$ acts as the conjugate base. Therefore:

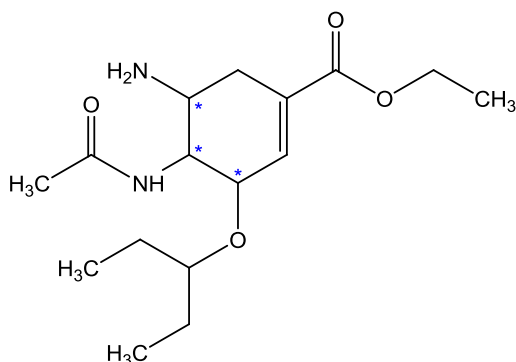
$$\text{pH} = \text{p}K_a(\text{CO}_2) + \log \frac{[\text{HCO}_3^-]}{[\text{CO}_2]} = 6.34 + \log \frac{24.0 \text{ mmol dm}^{-3}}{2.14 \text{ mmol dm}^{-3}} \approx 7.39$$

Note that the units of concentration do not need to be converted to mol dm^{-3} as long as they are identical in the numerator and denominator.

- (b) The molecule of aspirin contains a carboxyl group, which can dissociate to produce protons:
 $\text{CH}_3\text{C}(\text{O})\text{OC}_6\text{H}_4\text{COOH}(\text{aq}) \rightleftharpoons \text{CH}_3\text{C}(\text{O})\text{OC}_6\text{H}_4\text{COO}^-(\text{aq}) + \text{H}^+(\text{aq})$
As $[\text{H}^+]$ increases, the pH of the patient's blood decreases.
24. *Ranitidine*: H_2 histamine receptors in the parietal cells of the stomach lining.
Omeprazole: receptors of the proton pump (H^+/K^+ ATPase) in the parietal cells of the stomach lining.

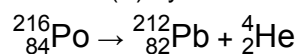
25. (a) Amino and ester.
Note that "amine" is a class name, not a functional group name.
- (b) To score the full mark, your answer may include any **two** hazards from table D.6.2.
- (c) Influenza is caused by viruses, not bacteria, so antibacterial drugs are completely ineffective against it. Viruses have no cell walls and no transpeptidase enzyme, which is targeted by penicillin. An attempt to use penicillin against a viral infection will only increase the resistance of bacteria to antibiotics and kill some beneficial bacteria.

26. (a)



- (b) Polarimeter.
- (c) 13.
- (d) Your answer should include any **one** of the following: IR spectroscopy, mass spectroscopy, UV-vis spectroscopy, X-ray crystallography, elemental analysis, chromatography, polarimetry, melting point determination.

27. (a) An alpha-decay decreases the atomic number (Z) by two units and the mass number (A) by four units. Therefore, ${}^A_Z\text{X}$ is ${}^{216}_{84}\text{Po}$:



- (b) According to section 1 of the data booklet, $N_t = N_0 \times (0.5)^{t/t_{1/2}}$.

If $N_0 = 100\%$, then:

$$N_t = 100\% \times (0.5)^{48.0/10.6} \approx 4.33\%$$

Alternative solution:

$$\lambda = \frac{\ln 2}{t_{1/2}} \approx \frac{0.693}{10.6} \approx 0.0654$$

$$N_t = N_0 e^{-\lambda t} = 100\% \times e^{-0.0654 \times 48.0} \approx 4.33\%$$

28. Anode (negative electrode):
 $\text{C}_2\text{H}_5\text{OH}(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{CH}_3\text{COOH}(\text{aq}) + 4\text{H}^+(\text{aq}) + 4\text{e}^-$
 Cathode (positive electrode):
 $\text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}(\text{l})$

IB Prepared Chemistry

Paper 1 answer sheet

Indicate your answers in the answer boxes provided.

1 A B C D

2 A B C D

3 A B C D

4 A B C D

5 A B C D

6 A B C D

7 A B C D

8 A B C D

9 A B C D

10 A B C D

11 A B C D

12 A B C D

13 A B C D

14 A B C D

15 A B C D

16 A B C D

17 A B C D

18 A B C D

19 A B C D

20 A B C D

Questions 21–30 are for
SL candidates only.

21 A B C D

22 A B C D

23 A B C D

24 A B C D

25 A B C D

26 A B C D

27 A B C D

28 A B C D

29 A B C D

30 A B C D

Questions 31–50 are for
HL candidates only.

31 A B C D

32 A B C D

33 A B C D

34 A B C D

35 A B C D

36 A B C D

37 A B C D

38 A B C D

39 A B C D

40 A B C D

41 A B C D

42 A B C D

43 A B C D

44 A B C D

45 A B C D

46 A B C D

47 A B C D

48 A B C D

49 A B C D

50 A B C D

IB Prepared Chemistry

Paper 2 answer sheet

Write your answers in the boxes provided.

1. (a)

[3]

.....

.....

.....

.....

.....

.....

(b)

[2]

Magnesium atom:

.....

Sulfur atom:

.....

(c)

[2]

Ionization energy:

.....

.....

.....

Electron affinity:

.....

.....

.....

(d) (i)

[3]

.....

.....

.....

.....

.....

.....

(ii)

[2]

.....

.....

.....

.....

(e) (i)

[2]

.....

.....

(ii)

[1]

.....

.....

(f)

[2]

.....

.....

.....

.....

2. (a)

[2]

.....

.....

.....

(b)

[1]

.....

.....

.....

(c)

[1]

.....

.....

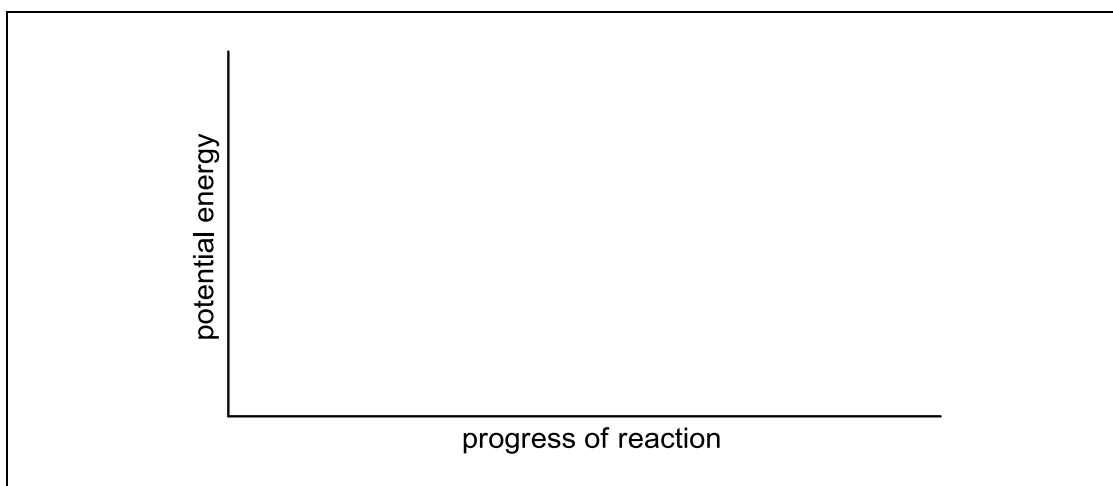
(d) (i)

[2]

T	p	Effect	Reason
decreases	constant		
constant	increases		

(ii)

[2]



(e) (i)

[1]

.....

.....

(ii)

[3]

.....

.....

.....

.....

.....

.....

3. (a) (i)

[1]

.....

.....

(ii)

[2]

.....

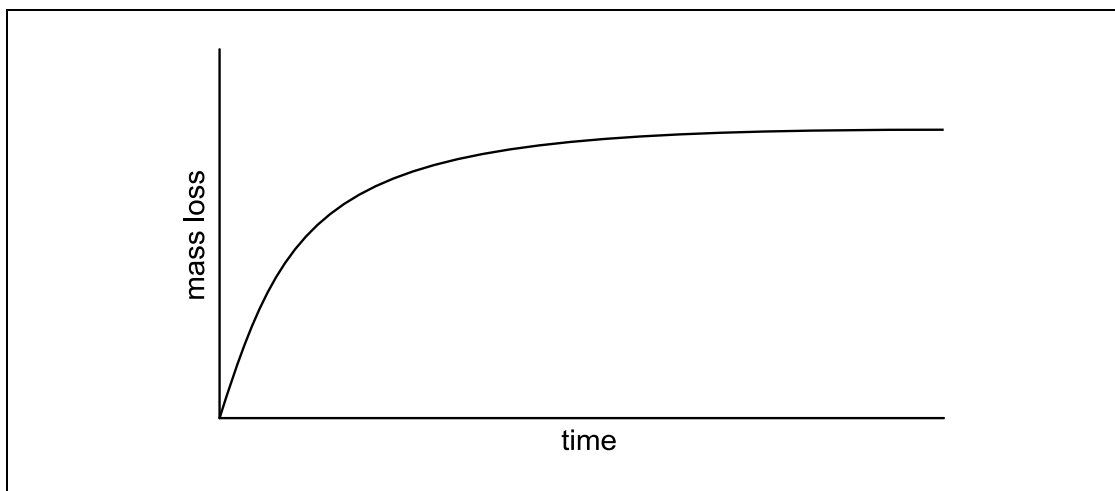
.....

.....

.....

(iii)

[1]



(b) (i)

[1]

.....

.....

(ii)

[2]

Experiment 1:

.....

.....

Experiment 2:

.....

.....

(iii)

[3]

.....

.....

.....

.....

.....

.....

(iv)

[2]

Accuracy:

.....

.....

Precision:

.....

.....

(v)

[1]

.....

.....

.....

4. (a)

[1]

.....

.....

(b)

[2]

<p>Reagents:</p> <p>.....</p> <p>.....</p> <p>Reaction conditions:</p> <p>.....</p>

(c)

[2]

<p>.....</p> <p>.....</p>

(d)

[1]

<p>.....</p> <p>.....</p>

(e)

[2]

<p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p>
--

The following questions are for HL candidates only.

5. (a) (i)

[1]

(ii)

[2]

.....

.....

.....

.....

(b) (i)

[1]

(ii)

[2]

Electron domain geometry:

.....

.....

Molecular geometry:

.....

.....

(iii)

[1]

(c)

[2]

.....

.....

.....

.....

(d) (i)

[1]

(ii)

[1]

Hybridization of C-2 in propene:

.....

Hybridization of C-2 in the organic product:

.....

6. (a) (i) [1]

.....

.....

.....

(ii) [1]

.....

.....

(iii) [2]

.....

.....

.....

.....

.....

(iv) [1]

.....

.....

(b) [1]

.....

.....

(c)

[3]

<p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p>

(d)

[2]

<p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p>

7. (a)

[1]

<p>.....</p> <p>.....</p> <p>.....</p>
--

(b)

[1]

<p>.....</p> <p>.....</p>

(c)

[1]

<p>.....</p> <p>.....</p>

(d)

[1]

.....

.....

(e)

[1]

.....

.....

(f)

[1]

8. (a)

[1]

.....

.....

(b) (i)

[1]

Oxidation state in $[\text{Ti}(\text{H}_2\text{O})_6]^{3+}$

.....

.....

Oxidation state in $[\text{TiF}_6]^{2-}$

.....

(ii)

[1]

.....

.....

.....

(iii)

[1]

.....

.....

9. (a)

[1]

.....

.....

(b)

[1]

.....

.....

(c)

[1]

.....

.....

.....

(d)

[2]

.....

.....

.....

.....

10. (a)

[2]

.....

.....

.....

.....

.....

(b)

[2]

Equation:

Reaction conditions:

.....

.....

(c) (i)

[1]

(ii)

[2]

Number of non-aromatic signals:

.....

Integration ratio:

.....

(iii)

[1]

.....

.....

End of Paper 2

IB Prepared Chemistry

Paper 3 answer sheet

Write your answers in the boxes provided.

Section A

1. (a) [1]

(b) [2]

(c) [2]

(d) [1]

(e)

[1]

<hr/> <hr/>

2. (a)

[2]

<hr/> <hr/> <hr/> <hr/>

(b)

[1]

<hr/> <hr/>

(c)

[1]

<hr/>

(d)

[1]

<hr/> <hr/>

(e)

[1]

<hr/> <hr/>

(f)

[1]

<hr/> <hr/>

(g)

[1]

<hr/> <hr/> <hr/>

Section B

Option A — Materials

3. (a)

[1]

<hr/> <hr/> <hr/>

(b)

[1]

<hr/> <hr/> <hr/>

(c)

[1]

<hr/> <hr/>

(d)

[3]

<hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/>

(e) (i)

[1]

<hr/> <hr/>

(ii)

[2]

<hr/> <hr/> <hr/>

4. (a)

[1]

(b)

[2]

<hr/> <hr/> <hr/> <hr/>

(c)

[1]

.....

.....

(d)

[1]

.....

.....

5. (a)

[1]

.....

.....

(b)

[2]

Polarity:

.....

.....

.....

Long hydrocarbon chain:

.....

.....

.....

(c)

[2]

Catalyst:

.....

.....

Conditions:

.....

.....

(d)

[1]

.....

.....

.....

6. (a)

[3]

.....

.....

.....

.....

.....

.....

(b)

[2]

.....

.....

.....

.....

7. (a)

[1]

.....

.....

(b)

[1]

.....

.....

(c)

[3]

.....

.....

.....

.....

.....

.....

Option B — Biochemistry

8. (a)

[1]

.....

(b)

[2]

(c)

[1]

(d)

[2]

Advantage:

Disadvantage:

9. (a)

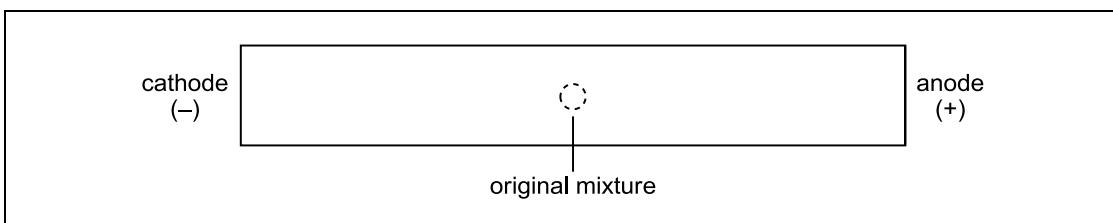
[2]

(b)

[1]

(c)

[2]



10. (a)

[3]

<hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/>

(b)

[1]

<hr/> <hr/>

(c)

[1]

<hr/> <hr/>

(d)

[2]

<hr/> <hr/> <hr/> <hr/>

11. (a)

[1]

<hr/> <hr/>

(b)

[1]

<hr/> <hr/>

12. (a)

[1]

<hr/> <hr/>

(b)

[1]

<hr/> <hr/>

(c)

[1]

<hr/>

(d)

[1]

<hr/>

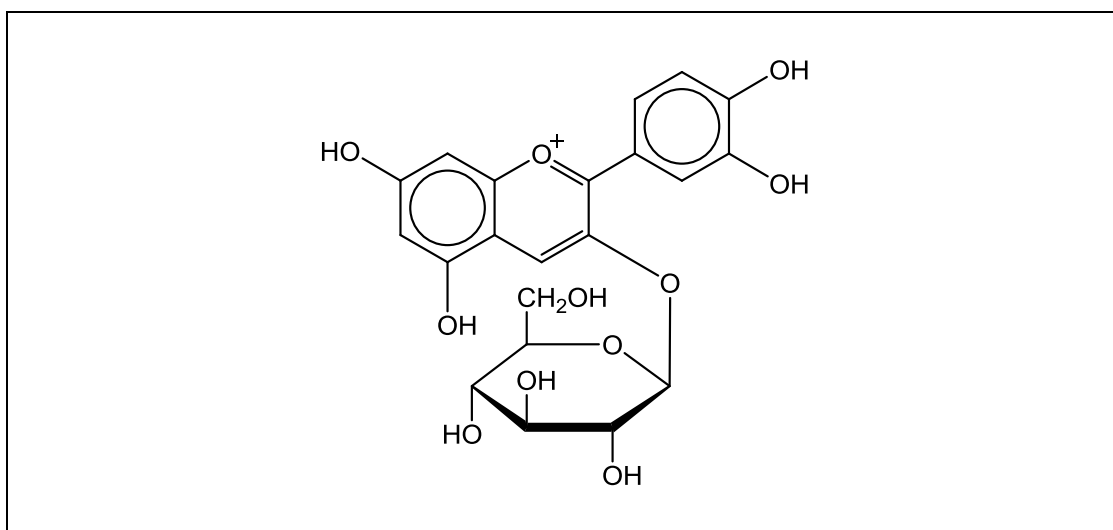
(e)

[1]

<hr/> <hr/> <hr/> <hr/>

13. (a)

[1]



(b)

[1]

.....

.....

(c)

[2]

pH = 3:

.....

.....

pH = 6:

.....

.....

(d)

[1]

.....

.....

Option C — Energy

14. (a) [2]

.....

.....

.....

.....

(b) [1]

.....

.....

(c) (i) [1]

.....

.....

(ii) [1]

(iii) [2]

Reaction type:

.....

Catalyst:

.....

(iv)

[2]

<p>Advantage:</p> <p>.....</p> <p>.....</p> <p>Disadvantage:</p> <p>.....</p> <p>.....</p>
--

(d)

[2]

<p>.....</p> <p>.....</p>

15. (a)

[2]

<p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p>

(b)

[2]

<p>.....</p> <p>.....</p> <p>.....</p>
--

(c)

[1]

16.

[2]

Letter	Radiation type
A	
B	
C	
D	

17.

[2]

18. (a)

[2]

Anode (negative electrode):

Cathode (positive electrode):

(b)

[2]

19. (a)

[2]

.....

.....

.....

.....

(b)

[1]

.....

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.....

.....

20. (a)

[2]

.....

.....

.....

.....

(b)

[1]

.....

.....

Option D — Medicinal chemistry

21. (a) [2]

(b) [2]

(c) (i) [1]

(ii) [1]

(iii) [1]

(iv)

[1]

22.

[2]

23. (a)

[1]

(b)

[1]

24.

[2]

Ranitidine:

Omeprazole:

25. (a)

[2]

(b)

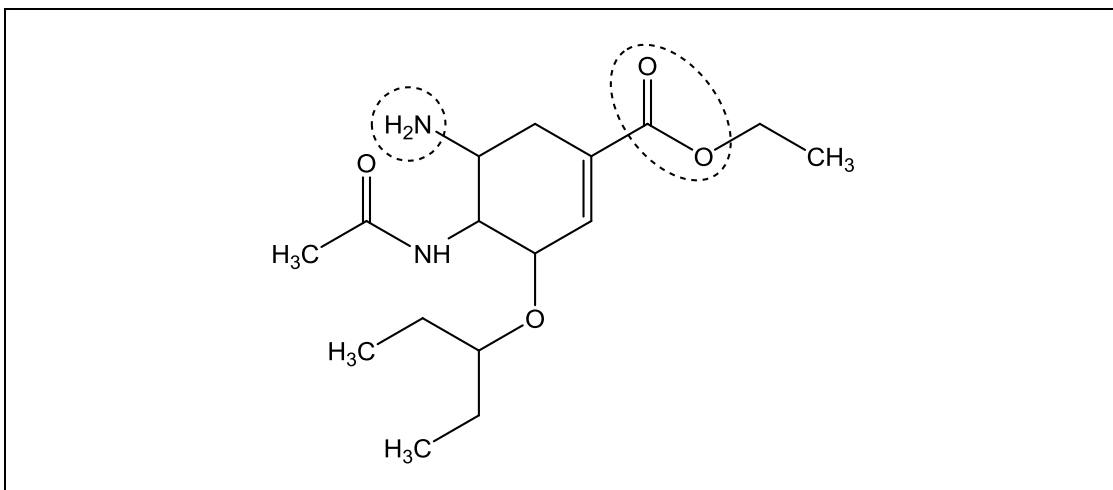
[2]

(c)

[2]

26. (a)

[1]



(b)

[1]

(c)

[1]

(d)

[1]

27. (a)

[2]

(b)

[2]

28.

[2]

End of Paper 3